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VOLUME II

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TRANSFER, AND COMMUNICATIONS

Final Report
for the Period
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NASA Contract NASW 3204

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PROGRAM IN INFORMATION POLICY

Engineering-Economic Systems Department
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Report Organization

Each of the papers in this volume is preceded by an abstract providing more information about its contents. The abstract also indicates the author(s) of the original paper. For easier reference, the abstract is labeled according to the outline scheme used above, i.e., II.A, II.B.1, and so forth. For ease of handling, the report comprises two volumes. Volume I contains Parts I (Executive Summary), and Part II (Technology Transfer). Volume II contains Parts III (Communications Policy) and IV (Space Commercialization).

ECONOMIC ASPECTS OF SPECTRUM MANAGEMENT

Robert D. Stibolt
October 1979

Abstract

This paper addresses problems associated with the allocation of a scarce resource—the radio frequency spectrum. The current method of allocation does not always allocate the resource to those most valuing its use. Because users of the spectrum are not required to pay the opportunity cost of their spectrum use (the benefits foregone when spectrum is not employed in its best alternative use) they are, in effect, being subsidized. Furthermore, users have little or no incentive to conserve their use of the resource by adopting efficient technology.

A number of schemes to encourage more economically efficient use of the resource have been proposed. The first part of the paper sets out economic criteria by which the effectiveness of : source allocation schemes can be judged, and offers some thoughts on traditional objections to implementation of market into frequency allocation.

The second part of the paper discusses the problem of allocating orbit and spectrum between two satellite services having significantly different system characteristics. The problem is compounded by the likelihood that one service will commence operation much sooner than the other. Some alternative schemes are offered that, within proper international constraints, might achieve a desired flexibility in the division of orbit and frequency between the two services domestically over the next several years.

ECONOMIC ASPECTS OF SPECTRUM MANAGEMENT

Robert D. Stibolt

Report No. 25
October 1979

National Aeronautics and Space Administration

Contract NASW 3204

PROGRAM IN INFORMATION POLICY

Engineering-Economic Systems Department
Stanford University   Stanford, California 94305

Abstract

This paper addresses problems associated with the allocation of a scarce resource--the radio frequency spectrum. It is observed that the current method of allocation very likely does not allocate the resource to those most valuing its use. Because users of the spectrum are not required to pay the "opportunity cost" of their spectrum use (defined as the benefits foregone by not employing the resource in its best alternative use) they are, in effect, being subsidized. Furthermore, there is little or no incentive for them to improve and conserve their use of the resource. If anything, incentives run counter to this goal.

A number of schemes to encourage more economically efficient use of the resource have been proposed. These range from institution of a free market in radio frequency rights to implementation of federally administered usage fees. The first part of the paper sets out economic criteria by which the effectiveness of resource allocation schemes can be judged, and offers some thoughts on traditional objections to implementation of market characteristics into frequency allocation.

The second part of the paper discusses the problem of dividing orbit and spectrum between two satellite services sharing the same band, but having significantly different system characteristics. The problem is compounded by the likelihood that one service will commence operation much sooner than the other. Some alternative schemes are offered that, within proper international constraints, could achieve a desired flexibility in the division of orbit and frequency between the two services domestically over the next several years.

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I.   WELFARE ECONOMICS AND SPECTRUM MANAGEMENT

     a. Introduction

         Much has been written in recent years about how the Federal

Communications Commission (FCC) and the Interdepartmental Radio

Advisory Committee (IRAC) allocate a scarce resource - the radio

frequency spectrum. The interest in this subject stems from the

fact that radio spectrum [1] is allocated in a manner so radically

different from that for most other resources in our economy. From

the standpoint of economic efficiency, this method of allocation is

considered by many to be highly questionable.

         The present method of radio spectrum allocation [2] has its roots

in the Radio Act of 1927 (Public Law 69-632), the purpose of which was

stated in the preamble as follows [3].

>   ". . . this Act is intended to regulate all forms of interstate
>   and foreign radio transmissions and communications within the
>   United States, its territories and possessions; to maintain the
>   control of the United States over all the channels of interstate
>   and foreign radio transmission; and to provide for the use of
>   such channels, but not the ownership thereof, by individuals,
>   firms, or corporations, for limited periods of time, under
>   licenses granted by Federal authority, and no such license shall
>   be construed to create any right, beyond the terms, conditions,
>   and periods of the license."

         Most of the provisions of this act were later incorporated into

the Communications Act of 1934 (P.L. 73-416), the basis of the FCC's

current authority. In effect, the federal government nationalized

the radio spectrum, apparently out of the fear that continued unregu-

lated use would result in levels of radio interference rendering the

resource entirely useless [4].

As "trustee" of the resource, the federal government is charged with the following significant responsibilities:

Sec. 1, ". . . to make available, so far as possible, to all people of the United States a rapid, efficient, nation-wide and world-wide wire and radio communication service with adequate facilities at reasonable charges"

Sec. 303(c), "Assign bands of frequencies to the various classes of stations, and assign frequencies for each individual station and determine the power which each station shall use and the time during which it may operate"

Sec. 303(f), "Make such regulations not inconsistent with law as it may deem necessary to prevent interference between stations and to carry out the provisions of this Act: Provided, however, that changes in the frequencies, authorized power, or in the times of operation of any station, shall not be made without the consent of the station licensee unless, after a public hearing, the Commission shall determine that such changes will promote public convenience or interest or will serve public necessity, or the provisions of this Act will be more fully complied with"

Sec. 303(g), "Study new uses for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest"

These provisions underlie the present "modus operandi" of the Federal Communications Commission. As it is now, the FCC must decide how, and by whom, radio frequencies will be used [5].

Aside from the issue of the political implications of centralized control of an information medium (certainly not to be ignored in this case), the FCC faces the problem that plagues any central allocatory authority: insufficient genuine information to make intelligent judgments on how to distribute the resource under its purview. This is not to say that applicants and licensees are not eager to supply plenty of information, but it is information inevitably colored to reflect the vested interest of its supplier [6]. Sorting the

genuinely relevant information out of reams of data is an

unenviable task often far beyond the capability of an agency

with the FCC's resources.

One place market allocation appears to be generally superior

to administrative control is in the economy of information required

to guide resources to their highest valued use [7]. No single en-

tity needs to know who has the greatest need or who will make best

use of a resource. All relevant information about the marginal value

of a resource to those actively competing for its use is contained in

one number--the market price. In aggregate, the amount of information

in the economy can remain immense, but the decentralization of

decision-making eliminates the transaction cost associated with

transferring large amounts of information to a centralized authority,

and tends to ensure that decisions are based only on relevant

information [8].

Owen set out three serious flaws in present methods of radio

frequency allocation and assignment as follows [9]:

1) There is no formal mechanism for trading spectrum
   rights among users;

2) no price is paid for use of the resource;

3) the criteria by which users are chosen are vague and,
   from the standpoint of both quality and economic
   efficiency, often counter-productive.

Both the first and second flaws have significant impacts upon

innovation and the development of new services that often follow it.

Spokesmen for the development of new communications services often

find themselves in conflict with the FCC over whether or not frequencies

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will be allocated to potential new, but as yet non-existent, services. They correctly perceive that failure to secure frequency allocations now for future services may preclude those services from coming into being. Without some assurance that these allocations can be obtained, people hesitate to invest in development and construction of equipment that would be rendered useless by shortages of usable frequencies.

One cause of this dilemma is the effective nontransferability of either present or future radiation rights [10]. Under the present system, there is often no incentive for old users to yield to new, even when the new user would be willing to pay the older user much more than the value that the old user would assign to his unit of spectrum. If old users perceived spectrum use as having a price, either because they paid a fee, or because they could have all or part of their radiation rights bought out by new users, then there would indeed be an incentive for old services to yield use of the spectrum to more valuable new services. In such a world, providers of new services would know that, when the time came, they would be able to obtain frequencies. The only uncertainty would be over what the price would be (even this uncertainty could be reduced by an appropriate futures contract with a present user). From the standpoint of risk, this would be preferable to the current system, where the new service has no assurance that spectrum with the desired characteristics can be obtained in the desired amounts, regardless of its willingness to pay the price.

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Certain implications of nontransferability of any rights can
be gl ned from the following proposition, derived from welfare
economics:

> If any number of parties enter into a transaction of their
> own volition, and if the transaction has only nonnegative
> impacts on nonparticipating parties, then social welfare
> is unambiguously increased by the transaction.

If there is a nonparticipating party on which there is an adverse
(negative) impact, it may still be possible to expand the definition
of the transaction to include compensation to this party and satisfy
the above criterion. If parts of such expanded transactions are allowed
to be only potential (that is, transactions that could take place but
won't necessarily) then the above becomes the familiar "Kaldor Criterion"
[11].

If transactions of the type above are blocked, as present communi-
cations law dictates that they are, then society has foregone an in-
crease in its welfare. This is the primary reason for the economist's
interest in the shortcomings of current radio frequency allocation
methods.

In a world of perfect markets, all transactions would be of the
type described above (to be perfect, impacts upon nonparticipants
should be strictly zero). Furthermore, when certain familiar assump-
tions are made about the preferences of the participants in this
market (nonsaturation, etc.) and transactions costs (they are zero or
sufficiently negligible) then the resources allocated by the market
will be allocated in an economically efficient manner. This

economically efficient allocation of resources is a necessary, but not sufficient, condition for maximization of social welfare (however, within reason, it may be defined. Arriving at this definition is the essence of the political problem.).

The stated proposition can be applied even when markets are imperfect, though greater scrutiny of a transaction's effects upon the welfare of third parties is generally required. The presence of monopolies may tend to create more equity and externality problems, but it is still possible, within these constraints, to define certain resource allocations as being "better" or "worse" than others.

Besides inhibiting transfer of rights, "zero price" spectrum use reduces incentive to economize on its use. Thus, spectrum (and orbit too) is always perceived as being in short supply. NASA, for example, sets out the coming saturation of limited spectrum and geostationary orbit resources as the motivation for initiating a research and development program to open the 20/30 GHz band to use by communications satellites. Technologies that make use of the resource more extensive (for example, higher power traveling wave tubes making higher frequencies usable) and more intensive (multibeam antennas, digital compression, etc.) are seen as a way to increase the resource supply, and thus close the gap between supply and demand. Others, however, have noted a tendency of technology based efforts to increase supply to also increase demand, by making new services possible [12]. Thus, the technologist becomes much like the dog chasing its tail--running faster and faster but never quite catching up.

This perceived shortage is a consequence of the fact that no price is paid for use of the resource. In a properly functioning market, no shortage would exist. In such a world, NASA would see its objective not as closing the gap between supply and demand, but as lowering the resource cost to the user (or, alternatively, expanding the number of services that can be offered on a profitable basis). Also, there would be greater incentive for private sector users to develop ways to use the resource more intensively, since this would directly benefit them financially. NASA's emphasis would probably shift towards (higher risk) extensive development.

Finally, conventional cost-benefit analysis will tend to misestimate the return on communications R&D. Many of the "benefits" measured by such analyses are, in part, measures of the cost of misallocating a resource. Many of the services now excluded (or limited) by the present spectrum allocation and assignment process may have greater value than some of those included (a frequently cited example of what appears to be such a case is land mobile radio vs. UHF television frequency allocations). Likewise, costs associated with some high value services now operating will be overestimated due to their being required to use a suboptimal mix of inputs. If the resource were allocated in a manner that was "economically efficient," then one could be sure that it was only marginal services whose costs and benefits were being compared, and that all cost estimates were being based on optimal input mixes. As it is now, most studies of this sort are largely "stabs in the dark."

b. Economically Efficient Spectrum Use

The word "efficiency" is generally used in several different contexts, often leading to confusion. For example, some engineers characterize efficient spectrum use as accomplishment of a given task by use of technology that minimizes required bandwidth, power, and area of unwanted spillover. Under this definition, efficient use of the resource is identified with minimum possible use, even though such minimal use would require state-of-the-art (expensive) technology across the board.

Another (and I would argue more reasonable) approach to judging efficiency of spectrum use invokes economic efficiency as the chief criterion. Economic efficiency is characterized by optimum use of all resources required for production of a given output. Here, "optimum" means minimization of the total opportunity cost of all inputs used to produce a given output. Opportunity cost is defined as the value of benefits foregone by not employing a given input (i.e., spectrum) in its best alternative use. As an aside, it can be noted that, in a perfect market economy, aggregate opportunity cost minimization corresponds to aggregate profit maximization [13]. If the total opportunity cost of all inputs used in a production process exceeds the value of output, then the activity in question is unprofitable relative to other possible activities; thus, one expects resources to flow to the other (more profitable) activities.

Economic efficiency criteria treat spectrum as just one of many inputs into a given output. Furthermore, inputs can be

substituted for each other. For example, one can use less spectrum
by using more sophisticated technology, and vice versa. In deciding
how much of each to use, the producer (here a common carrier or
broadcaster) compares the relative cost of each, and then alters
the mix of inputs so as to minimize total cost.

Under the present allocation methods, the cost of spectrum use
to the user (zero, assuming one can get the assignment) does not
reflect the opportunity cost (which is greater than zero, since use
of a given frequency necessarily excludes certain other potentially
worthwhile uses of the same frequency in the same area). The result
of this is that common carriers, broadcasters and other users of the
spectrum are motivated to substitute greater spectrum use, which
they perceive as cost-free, for use of more expensive technologies
that reduce or eliminate spectrum use. At the same time, potential
spectrum users who cannot get an assignment from the Federal Communi-
catins Commission (FCC) are forced to substitute alternative resources
in the production of the goods or services they wish to provide, or
forego production altogether. Under the FCC's current allocation
and assignment scheme, there is nothing to ensure that spectrum is
allocated among potential users in such a way as to maximize its con-
tribution to society's aggregate economic product, and good reason
to believe that it is not.

The solution to this problem is not, as is often proposed, to
accommodate all possible users of the spectrum by use of technology
sophisticated enough to allow everyone who wishes to use the spectrum
to do so. This kind of approach seeks to reduce the opportunity cost

of spectrum use to zero by substitution of other resources (such
as more sophisticated equipment), but fails to recognize that this
requires an increase in the opportunity cost of the other resources
used in the production of a specified level of output. The total
opportunity cost of all inputs is unlikely to be minimized by such
an approach.

The best (in the sense of economically efficient) solution to
the spectrum allocation problem can only be achieved if the cost
of spectrum use to the user can be made to reflect its opportunity
cost. If this could be achieved, competitive economic forces would
then tend to push spectrum assignments into the hands of those
groups or individuals making the most economically productive use of
the resource.

If the cost of the spectrum use truly reflected opportunity
cost, spectrum use by new industries (such as a Land Mobile or
Broadcast Satellite Service) that proved to be more profitable than
existing uses would drive up the cost of spectrum use to the point
where the existing users would be forced to reduce or eliminate
their use. Thus, new communications services would not face uncer-
tainty about whether or not spectrum assignments could be acquired
that might otherwise stifle their growth.

There are a number of ways in which the cost of spectrum use
could conceivably be made to reflect opportunity cost. Among these
are institution of a free market for spectrum where assignments can
be bought and sold, institution of a spectrum use fee by a centralized
regulatory authority, or some mix of markets and regulation. The

market's approach alleged drawback resides in the difficulty of
defining and enforcing spectrum property rights (although it can
be effectively argued that this same problem plagues the current
system). The drawback to centralized allocation with usage fees
is that an overwhelming amount of information is required in order
to accurately calculate fees that reflect opportunity cost (the
shadow pricing problem).

Nevertheless, definite improvement in the current FCC alloca-
tion and assignment process can very likely be achieved, even
though a "best of all possible worlds" solution may be impossible.
Allowing parties now holding licenses to openly buy and sell all
or part of their frequency assignments would institute market char-
acteristics tending to lead to more efficient spectrum utilization.
In spite of the evident merit of applying such market mechanisms
to the allocation of spectrum, however, there remain some tradi-
tional objections that must be addressed [14].

c. The Property Rights Problem

It is generally agreed that market mechanisms cannot be
successfully introduced into spectrum allocation without first
arriving at a workable definition of spectrum property rights. It
has been argued that transferable rights for a resource as ethereal
as the radio spectrum could become very complicated indeed. For
example, determination of who is liable for interference experi-
enced by a certain party would not be trivial in the case where the
interference is caused by intermodulation (although, again, this is

no different from the current situation). However, it would be premature to conclude, based on this alone, that enforcement costs [15] for transferable spectrum property rights need be prohibitively high.

The relatively low cost of enforcing property rights in more "concrete" resources, such as land, does not result from the definition of these property rights being any simpler than those proposed for spectrum. A small amount of reflection on the nature of land property rights reveals that they are, in fact, a very complicated set of rights, none of which are absolute in nature. For example, landowners may keep trespassers out, but not kill them; grow corn, but not marijuana; make noise, but not so much that their neighbors can never sleep. Zoning laws make these rights even more restrictive. Land property rights are never exclusive in the sense of society abdicating all control over land use.

It is not so much the level of complexity in a right's definition that determines enforcement costs, but certainly what the right entails. If A uses B's land without B's authorization, there is little doubt that a court will find A liable for damages to B. Certainly about what the outcome of an adjudication will be tends to deter events of this kind from occurring. The disputes most likely to end up in court are those associated with fuzzy delineation of a right. For example, the level of noise A is allowed to make on his/her property is generally not well defined. If A's turbine test facility is sufficiently close to neighbor B's recording studio, one expects there is a good chance the two will end up in court. Sufficient

precision in the definition of property rights would go far

towards keeping spectrum users out of court.

The other component significantly affecting enforcement cost

is the cost of detection. In the land rights example, it was

reasonable to assume that B would detect A's violation of B's

property right with high probability at very little cost. However,

if the probability of detecting A's violation (and identifying A

as the offender) is sufficiently low, and the penalty incurred by A

upon being detected is sufficiently low, one might expect A to vio-

late B's right even when it is certain that A would lose to B in an

adjudication.

This last problem can be formally illustrated in the following

manner:

> a = state of the world in which A's violation
> goes undetected;
>
> b = state of the world in which no violation
> takes place;
>
> c = state of the world in which A is caught
> and punished;
>
> p = the probability A assesses of being caught;
>
> u(x) = utility of state of the world x.

Making the assumption that $U(a)>U(b)>U(c)$, construct the func-

tion $(1-p)U(a)+pU(c)$. This is A's expected utility of violating

B's right, and is a strictly decreasing function of p. Furthermore,

there exists a p between 0 and 1 such that $U(b)>(1-p)U(a)+pU(c)$ for

all probabilities greater than p. That is, above some minimum proba-

bility of detection, A will not wish to violate B's right. If one

accepts the notion that the perceived probability of detection tends

to be positively correlated with society's actual expenditure on detection, then one can conclude that an increase in this expenditure will tend to decrease the number of people violating other people's rights. Whether the expenditure that maximizes the net social dividend (defined as the value of the provisions prevented minus the cost of detection) will be within reasonable limits is an as yet unresolved question for spectrum rights.

Also, observe that an increase in the penalty for a violation would decrease $U(c)$ and, therefore, the minimum detection probability above which A would not violate B's rights. Thus, under both the current and market techniques for spectrum allocation, there is some flexibility in that higher penalties can be, to some extent, substituted for detection capability, thereby lowering enforcement costs [16].

DeVany et al. [17] have proposed definition of spectrum property rights in terms of hours of transmission, in and out of band limits on radiated power outside a specified geographical area, and bandwidth. The notion is that property rights defined in these "output" terms would be much easier to transfer in whole or part than rights specified in terms of inputs, such as transmitter power or antenna height. In the case of satellites, system performance requirements are already defined in terms of limits on power-flux-density (PFD) over specified geographical areas. This closely approximates the Time-Area-Spectrum (TAS) property right advocated by DeVany et al., though additional complications are introduced by the possibility of interference on earth to space transmissions, especially when the

power levels of these uplinks differ significantly. These

additional complications manifest themselves in the form of

the resource called "orbit." Segments of the geostationary arc

in space are the counterpart of areas of geographical coverage

on earth. Any discussion of satellite systems must account for

both.

d. Spectrum Monopoly

Besides enforcement costs, concern has been voiced over the

strong possibility that markets in radio frequencies would be

largely monopolized by the national broadcasting networks in some

bands, and by AT&T in others, in an attempt to squeeze out competi-

tion. This tendency could be especially severe in the case of AT&T

where regulated rate of return monopoly services could be used to

cross-subsidize services offered in competitive markets. In princi-

ple, AT&T might attempt to squeeze out competitors by buying up

spectrum, thereby raising its price to competitors and reducing the

volume of services they are able to offer. The standard response

to this concern--that antitrust laws can respond to such efforts in

the usual manner--is not entirely satisfactory in a time when many

large corporations have already demonstrated the capability to drag

such proceedings out for years. It would be far preferable to avoid

this situation if at all possible.

On the other hand, there are numerous ways in which the tele-

phone company can cross-subsidize services without resorting to

spectrum hoarding at all. Spectrum hoarding would succeed as a

squeeze out technique either by completely excluding competitors

from use of the spectrum or by forcing them to charge higher prices,

allowing the monopoly to undercut them. Total exclusion would seem

to make what is occurring too obvious. Hoarding just enough to

drive up the competition's prices to where they can be undercut

would seem to be a roundabout way of achieving something that could

be more easily achieved without hoarding spectrum (i.e. instead of

buying up spectrum to hold idle, why not just directly undercut the

competition's price?).

Finally, it is not clear that a spectrum market heavily domi-

nated by a regulated monopoly would be worse than the current situ-

ation, nor is it clear that the AT&T monopoly is any more constrained

by the current FCC from undesirable market practices than they would

be if spectrum were allocated by the market place. There is no

reason to believe that monopoly or oligopoly could not be just as

effectively regulated within the context of a market system as with-

out. This particular objection is largely beside the point.

e. Equipment Lifetimes

An oft-cited argument for maintaining the status quo is that the

rigidity of present spectrum allocation methods is necessary to pro-

tect the integrity of investment in long-lived radio equipment. The

fallacy of this argument lies in the failure to distinguish between

the "technical" and "economic" lifetime of equipment. Technical

lifetimes may be very long indeed, but it is the economic lifetime

that is relevant in economic decisions. Tax and depreciation policies

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in the United States, coupled with the rate of innovation and
resulting shifts in demands, tend to make the economic lifetimes
of most technologies significantly shorter than their technical
lifetimes. Innovation in the computer industry, for example, has
been so rapid that most machines are scrapped and replaced long
before there is any danger of their wearing out.

Economic decisions always involve the comparison of present
and expected future alternatives in the present moment. One does
not continue to fly Ford tri-motors simply because the equipment
has not worn out if conditions of demand are such that the profita-
bility of flying jet aircraft is greater. In fact, one of the
strongest arguments against the rigidity of the present system may
be that it stifles innovation in communications by favoring existing
users at the expense of innovative new users. Airlines wishing to
fly new aircraft have little difficulty obtaining pilots or fuel
used by airlines operating older aircraft when conditions of demand
warrant it, but anybody wishing to offer a new radio service may
have great difficulty obtaining spectrum from existing users,
even when the demand for the new service is high.

f. Indirect Prices for Resource Use

A not uncommonly heard objection to pricing spectrum use per
se is that users already pay an indirect price through their invest-
ment in radio equipment and operating expenses. However, attempting
to apply this argument to other analogous situations in the economy
reveals its weakness. Cars and gasoline, for example, like radio

equipment and radio spectrum, are both complements and substitutes
(i.e., more fuel efficient cars can be substituted for greater
gasoline consumption, yet the two are always used together). One
would be on very weak ground indeed if one attempted to argue that,
because people must buy cars to use gasoline, charging a price of
zero for gasoline would not lead to inefficient use of the resource.
Based on this premise, one could make a strong case that the govern-
ment should completely subsidize gasoline use for reasons of equity.

If any conclusion can be reached from the ongoing debate over
the viability of spectrum markets, it is that further theorizing is
unlikely to resolve the question. The economic case has been made.
Just as the theoretical physicist must at some point take predic-
tions to the laboratory before further theoretical progress can be
made, so it is that economists, both pro and con, must attempt an
"experiment" on the viability of spectrum markets before confidence
can be placed in their conclusions. Such an experiment for land
mobile radio services has already been proposed by Dunn and Owen
[18]. Along these lines some thoughts on how market techniques
could be applied to the assignment of orbit-spectrum to satellites
are presented in the next section of this paper.

II. MARKET ALLOCATION OF ORBIT-SPECTRUM FOR SATELLITE SERVICES

At the time the first man-made earth-orbiting satellites were
launched, few expected or believed possible the explosion in the use

of communication satellites that has occurred. Yet, problems

resulting from this rapid growth illustrate the drawbacks in the

current method of frequency allocation and assignment. There are

few places where the need for administrative flexibility is more

apparent than in the allocation and assignment of frequencies to

services undergoing rapid technologically induced changes.

From the standpoint of system performance, optimum frequencies

for satellites lie between about 1 and 10 gigahertz--the so-called

"space window." Because this part of the spectrum was already

heavily occupied by the time communication satellites went into

service, only one of the three bands currently allocated to communi-

cation satellites falls within this region (4/6 gigahertz band).

The other two bands (12/14 gigahertz and 20/30 gigahertz) require

substantially higher transmission powers to overcome effects of

atmospheric attenuation. Of these, the 12/14 gigahertz band is only

now coming into use while the technology to make the 20/30 band use-

able remains in the future. It is highly doubtful that the present

approach to frequency allocation has minimized the aggregate cost of

providing all services, both space and terrestrial, using frequen-

cies above one gigahertz.

Before proceeding with the discussion of orbit and frequency

allocation for satellite services, it is necessary to consider the

international context of the orbit-frequency allocation and assigned

problem.

The International Telecommunications Union (ITU) allocates fre-

quencies to services on a worldwide basis. This is achieved through

administrative radio conferences in which ITU member nations attempt
to arrive at a consensus as to how radio frequencies will be used.

Because its success is based on consensus politics, the ITU
must attempt to minimize the international constraints on domestic
decisions about frequency use within a particular country. The
United States, for one, has traditionally argued for the maximum
flexibility in determination of how a nation will use frequencies
within its borders. Services offered in one part of the world fre-
quently will not even exist in another part. Consequently, strict
worldwide allocation of frequencies would lead to tremendous waste
in resource use.

The U.S. is fortunate in the respect that, within its region
of the world, only a handful of nations are in potential conflict
over use of orbit and spectrum. This contrasts with the European
situation where many developed nations are concentrated within a
relatively small geographical region. Thus, it was tentatively con-
cluded by a 1974 Rand Corporation report that, except for Canada,
the probable demand for satellite systems of other countries in the
western hemisphere (ITU Region 2) can be met without special coordi-
nation with U.S. systems [19]. In fact, most of the orbital arc best
suited for use by South American nations does not coincide with seg-
ments best suited for U.S. and Canadian systems.

If this conclusion is indeed true, then reliance on market tech-
niques for domestic satellite orbit-spectrum assignment becomes a
much simpler political problem internationally than if domestic and
international assignments cannot be decoupled. More is said about
this shortly.

While people tend to describe satellite systems in terms of
the services they provide, it is often useful to think of them
purely in terms of their system characteristics.· High-powered
satellites, such as those being considered for space broadcasting,
offer the possibility of small diameter (less sensitive) earth
station antennas, thus allowing for systems employing many rela-
tively cheap earth stations. Systems in the fixed satellite ser-
vice generally employ relatively few earth stations using large
diameter (more sensitive) antennas and low powered satellites.
Interference between the two types of systems tends to be more
severe than interference between systems of the same type. Two
reasons for this are, 1) even though larger antennas have rela-
tively high gains, they also have sidelobes that can be illuminated
by interfering satellites and, 2) when the interfering satellite is
transmitting a higher power density than the satellite transmitting
the desired signal, then illumination of the sidelobe results in
relatively more interference noise in the receiver.

Approaches to sharing between services using the two system
types described have been studied relatively extensively and are
fairly well understood [20]. The unsolved problem lies not in how
to share between the two services but in how to determine, on the
basis of future utility, how much orbit-spectrum must be received
for each. If the future demand and course of technological develop-
ment for each service could be predicted with certainty, there would
be no problem in deciding how much orbit-spectrum to allocate to
each service at any given time. The difficulty arises both from the

likelihood that one service--the fixed satellite service, will grow

more rapidly within the next few years than the other--the broadcast

satellite service, and from uncertainty about what technologies will

become available to alleviate sharing problems between the two.

One question one might ask is: Should spectrum be held idle

for the future use of a service that might possibly come into

existence but is not certain to do so? Holding spectrum idle neces-

sarily excludes its use by currently viable services. The opportun-

ity costs incurred may very well outweigh the discounted future

benefits of the service for which the spectrum is being reserved.

It is unlikely that a satellite service expected to come into exis-

tence many years down the road could be justified if this were to

require that a significant amount of usable spectrum be held idle

for this entire period.

At least one person, Dr. Charles Jackson, has propose a world-

wide orbit-spectrum market for satellites [21]. Under the ackson

proposal, orbit-spectrum rights are preallotted to each ITU nation.

Nations may then lease their rights (which specify a band of frequen-

cies and a certain number of degrees of the geostationary arc loca-

tionally unspecified) to the highest bidder through a market run by

an international body (the IFRB). The rent from the lease of an

orbit-spectrum right goes to its "owner." Once a system operator

has acquired enough rights to protect himself from interference, he

registers his satellite system with the IFRB, just as at present.

Jackson's premise is that this approach would defuse much of

the growing political opposition that developing nations have to use

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of the orbit and spectrum by the developed nations without
requiring that economic efficiency be sacrificed. Jackson states
that, "the arguments for the necessity and possibility of a
spectrum market for international satellites are even stronger
than the arguments for the use of market allocation for many domes-
tic spectrum uses. Both equity and efficiency considerations are
involved in the allocation of the orbital-frequency resource. A
well designed market system should be able to separate these two
problems" [22].

Unfortunately, there is reason to question the last statement.
Much of what occurs in the international forum is heavily colored
by ideology that may not even accept the principles outlined by
Jackson and the first part of this paper. Even if orbital slots
that could be sold or leased were preallocated to every nation in a
manner deemed equitable (a proposal counter to traditional U.S.
positions), several political problems would still remain. Some
nations, initially finding relatively few buyers for their orbital
rights (and all buyers being from developed nations), might see them-
selves as victims of the monopsony power of the developed nations.
Coalitions of nations might decide that the political advantages
gained in other areas by using their allotted orbit-spectrum rights
for leverage would outweigh the relatively small revenues they might
receive from leasing them to users.

Problems of both sorts above have stalled the United Nations
Conference on the Law of the Sea for a number of years on the question
of deep seabed resource development. One can make a reasonable case

that leasing of deep seabed tracts by an international authority
to high technology companies for a limited term of years at a
price roughly approximating the economic rent of the activity is
an equitable way to proceed with the development of deep seabed
resources, especially when the proceeds from the lease are redis-
tributed to lesser developed nations. However, it is only recently,
after several years of negotiation, that ∴ ,ie of the lesser developed
nations have begun to acknowledge that only ∴∴ economic rent, and
not the entire revenue, from these activities should be subject to
redistribution. Many nations, seeing that they have little to gain
at best from deep seabed resource development have sought to use
the issue for political leverage. There is reason to believe that
much of the same kind of thing would make implementation of the
Jackson proposal on a worldwide scale difficult, regardless of merit.
However, it might be possible, as will be discussed, to employ a
regional or even domestic variation of the Jackson plan.

At present, three approaches to allocation of the 11.7 to 12.7
GHz (downlink) band appear to have reasonable probabilities for
adoption in ITU Region 2:

1. Rigid Allotment Plan with EIRP's, orbital spacing,
   frequency assignments specified; slots, channels
   assigned to nations.

2. Continuation of first-come, first-served principle;
   fixed and broadcasting satellites sharing the band,
   broadcasting satellites constrained to orbital arc
   segments from 75° - 95° W (North America) and 140°
   - 170° W.

3. Continuation of first-come, first-served
principle, separation of services by frequency.

The third approach listed characterizes the expected U.S.
position at the 1979 World Administrative Radio Conference. How-
ever, there are two ways to divide fixed and broadcast satellite
services by frequency, only one of which is acceptable to U.S.
interests. For example, the FCC's Tenth Notice of Inquiry (Docket
20271) recommended that the broadcasting satellite service be given
a primary allocation in the 12.2 to 12.75 gigahertz band (shared
with terrestrial fixed and broadcasting services), and that the
fixed satellite service be given a primary allocation in the 11.7
to 12.2 gigahertz band. This arrangement would require either a
power-flux-density limit on broadcasting satellites or a detailed
frequency coordination plan between broadcasting satellites and
terrestrial services, and would cause decreased geographical flexi-
bility. Too stringent power-flux-density limits might preclude the
use of earth terminals small enough for low-cost direct satellite-
to-home broadcasting.

While some (mostly Region 2 countries interested in satellites
primarily for broadcasting) deem this last aspect to be bad, the econ-
omist would note that if the value of the additional fixed satellite
services that can be offered because of power-flux-density limitations
outweighs the additional value of direct broadcasting from satellite
to home (as opposed, for example, to broadcast from satellite to
community area TV reception stations) then this would be the economi-
cally efficient solution. High powered broadcast satellites required

for direct broadcast may require the use of more orbit and spectrum
than is justified by the additional aggregate economic value.
Lower powered broadcast satellites broadcasting to community area
TV reception stations would generally allow more fixed satellite
services to be offered in the same segment of orbit.

Although this latter solution very likely is the one that maxi-
mizes the aggregate economic value of the services using the band,
most of the benefits from this approach accrue to nations not wish-
ing to use broadcast satellites (mostly developed nations). Even
though aggregate economic value is maximized, all parties may not
be better off than under alternative schemes. Unless some way is
found to redistribute benefits among nations (Jackson's satellite
market being one possibility) under the plan proposed by the U.S.,
stiff opposition can be expected.

An alternative suggested allocation includes both broadcasting
and fixed satellites in the 11.7 to 12.75 gigahertz band, with
higher powered satellites (i.e., broadcasting) initially assigned
to the 11.7 and 12.2 band and lower powered satellites (in the fixed
satellite service) initially assigned to the 12.2 to 12.75 gigahertz
band. It has been argued that this proposal makes (technically)
efficient use of the orbit and spectrum by grouping satellites of
similar characteristics and initially constraining higher powered
satellites to those frequencies shared with few terrestrial services
(making sharing with terrestrial services easier). One objection to
this flexible assignment scheme is that accommodations for broadcast-
ing satellites could disappear if faster-growing fixed satellite

services end up requiring the lower part of the band as well. Allowing the fixed satellite service to use the lower part of the band at all may incur international opposition from other Region 2 countries wishing to use this part of the band only for broadcasting satellites. On the other hand, insistence by these countries that the 11.7 to 12.2 gigahertz band be held idle indefinitely, even in the face of expanding demand for fixed satellite services, might be unacceptable to the U.S., and very likely economically inefficient.

If frequency division of the sort proposed by the U.S. is not adopted at WARC 79 (and this is considered by many to be unlikely), then the U.S. will be faced with the likelihood of an orbit segmentation plan (approach #2 above) or an even less desirable allotment plan (approach #1). One conclusion from the preceding discussion is that, however undesirable the approach ultimately adopted is, the U.S. would be much better off if the orbit-spectrum rights adopted are marketable (transferable) than if they are not. Then, at least, the FCC could go into the world market to buy them or lease them from other nations, if the domestic demand for satellite services warranted their doing so. If the adoption of a rigid plan appears imminent, it might be in the best interest of the U.S. (and other nations with similar concerns) to push for a regional market approach.

Even if such an approach proves to be infeasible throughout Region 2, it might still be feasible for a limited number of nations (i.e., Canada, the U.S., Mexico, Brazil) to collude and pool their allotments in order to achieve the maximum economic value from their

allotments (the market scheme would have to, of course, distri-
bute rents so that each participating party is better off than
they would be without such an agreement, but this is one thing
the market is well suited for). Mexico, for example, could lease
their slots to a foreign party until they were ready to use it
themselves (thus, making both better off)   Even if no other
nations wished to participate in such a scheme, the U.S. could
still employ the market approach in domestic distribution of its
allotment. Three approaches that could be employed domestically
or regionally are described in the following pages:

Policy Option 1 - A Domestic or Regional Market for Orbital Slots

Orbit-spectrum slots are auctioned to the highest bidder. These
assignments may then be bought and sold between services if no affected
parties are bypassed. The rights auctioned could be defined in a man-
ner similar to the Time-Area-Spectrum right proposed by DeVany et al.,
but would have both earth to space and space to earth components. On
the space to earth component, both in band and out of band maximum
permissible power-flux-densities could be stated for areas outside the
designated geographical area of coverage (with the out of band limit
applying within this area as well). The earth to space component
would have analogous limits (not necessarily the same) on in band
power levels outside the designated portion of the geostationary arc
and out of band power levels generally.

Rights bought by the highest bidder would be perpetual, but
transferable. As long as nobody else's rights are affected, parties

could even agree to alter power-flux-density limits as well as the amount of the earth's surface and geostationary arc designated by the right [23]. Furthermore, the relatively small number of systems would make enforcement of these rights fairly easy. Thus, the fixed satellite services, which would presumably be the initial rights holder, could at a later date, within the limits of their ability to share their assignment with a broadcasting party, sell all or part of their rights to a broadcasting party for a sum of money. The broadcasting party would presumably buy up additional orbit-spectrum rights from fixed service parties as long as their marginal revenue product from use of the resource exceeded that for the fixed satellite service.

Policy Option 2 - Administered Total Services Discounted Cost Minimization

The idea in this proposal is that both satellite services share frequency allocations and any time a new system, whether broadcasting or fixed, is proposed, the FCC (or the relevant multinational regulatory authority) must include this additional system in the available orbit-spectrum at the lowest aggregate cost over all users. This approach might require the new system to employ more expensive (spectrum conserving) technology than had been anticipated. It could also require previous systems using equipment requiring much orbit-spectrum to change equipment. Which systems must change equipment depends on what combination of changes admits the new system at the lowest aggregate cost.

This policy option is essentially the approach proposed by Lusignan and Russell, in which the party that saves the most gigahertz-degrees

per dollar expended is the party required to conserve spectrum.
It differs from coordination (the current procedure for transfer
of orbit-spectrum rights) in the respect that no transfer payments
between parties need take place for the efficiency of use to be
improved. Thus, earlier users need not receive scarcity rents at
the expense of later users, as is now the case. Unfortunately, in
order for the Lusignan-Russell scheme to work, regulatory authori-
ties must have all the information about technological options and
costs available for each satellite system. It is questionable
whether this is even remotely possible, and it is the author's
opinion that the information problems associated with administra-
tive remedies in general probably make the Lusignan-Russell proposal
less attractive than the other more market-oriented policy options
presented in this paper.

Policy Option 3 - Leased Rights Distributed by Auction

This proposal is similar to Option 1, except that rights are
leased by the central authority rather than sold outright. In fact,
the two could be mixed in a hybrid "bonus bid/royalty" scheme if
this were deemed desirable.

The lease rate would be a floating rate adjusting continuously
to the market value of assignments in the relevant part of the spec-
trum. This, unlike the outright market sale, would ensure that the
governing authority accrues all "windfalls" (which, however, could
be negative should the market price decline).

One argument favoring this approach over the outright market
sale is that bureaucratic organizations would be much more prone to

reexamine their resource needs if they leased rather than bought
spectrum. On the other hand, leasing at a floating rate would
burden the user with uncertainty over future prices that would not
be faced in an outright sale. Businesses will generally pay a pre-
mium to reduce uncertainty about the environment in which they
expect to be operating, especially when they are contemplating
longer-term investments. Furthermore, prices would have to increase
dramatically for a true windfall to occur in an outright sale of
spectrum assignments. Nevertheless, this option offers an alterna-
tive for those who feel that any kind of windfall accruing to a pri-
vate party under any conditions is unacceptable.

In fact, the choice of lease or sell could conceivably be based
on the particular nature of the parties involved. Alternatively,
leasing together with encouragement of options or futures contracts
could be employed. Under either system, coalitions of parties offer-
ing different services that could share an assignment would be capa-
ble of offering higher bids than a single service that excluded the
use of all other services from that part of the orbit spectrum. Both
would tend to lead to more efficient use of the resource.

Several observations can be made about the three policy options
described above. First, economic efficiency need not be coupled to
distributional equity. In fact, because economically efficient use
maximizes the aggregate economic value derived, it is possible that
nations participating in an economically efficient allocation scheme
could all be better off than they would be under an inefficient

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alternative (such as nontransferable nation by nation assignment
of channels and orbital slots). This last observation suggests
the possibility of multilateral collusion to adopt market or quasi-
market techniques in ITU Region 2 for assignment of orbit-spectrum.
Such a scheme could even be embedded by agreeing nations within
the rigid plan being advocated by some nations, provided transfera-
bility of allotted orbital slots or frequencies is maintained. Such
an approach should be examined as a possible fallback, should U.S.
positions at WARC 79, or at the proposed 1983 Region 2 conference
be rejected.

A more important observation is that all three schemes give
the designers/operators of satellite systems the incentives to
make correct trade-offs between technology and orbit-spectrum re-
source use—incentives that are either absent or distorted in the
present (zero-price rationing) administrative approach. Instilling
the correct incentives will be especially important if the number of
satellite orbital slots available to the U.S. is severely limited
by international orbit-wide planning. In fact, it is possible that
the same mechanisms that instill these incentives (payment of scar-
city rent by users) could play a role in reducing the attractiveness
of such worldwide planning even to those nations most enamoured with
it. Once the appearance of users getting something for nothing is
eliminated, the international political interest in orbit-spectrum
assignment might disappear.

III. EPILOGUE

Orbit-Spectrum is the only commercially useful space resource developed by mankind so far, but, hopefully, not the last. For those who believe other space resources will indeed be developed, orbit-spectrum serves as a useful prototype highlighting some of the problems development of other space resources can expect to encounter.

Fifty years ago, orbit-spectrum was a worthless resource. Today, this is far from being the case, as the continuing political conflict between nations over its allocation so vividly illustrates. Many of the lesser-developed nations have demanded that they be apportioned their fair share of the resource, even though they have no real intention of using it themselves. But, what made this once worthless resource so valuable?

The answer to this last question is, of course, technology-- specifically, technology developed by a handful of industralized nations. One might argue that, since orbit-spectrum is a nondeplet- able resource made useful only by the investment of these nations, it is only fair that they use it as they see fit. According to this view, leasing of orbital slots through an international authority would lead to accrual of economic rents by lesser developed countries (LDC's) not truly earned--thus, a leasing arrangement would be really quite generous to the LDC's.

Unfortunately, the LDC's don't see it this way. Some believe, rightly or wrongly, that the wealth of the industrialized nations was

accumulated by exploitation of what are now lesser developed
nations during the colonial period. They view orbit-spectrum as
one of many "common heritage" resources (i.e., not by their loca-
tion naturally belonging to any one nation) that should be evenly
distributed among the nations of the earth, but are likely to be
appropriated by the (first-come) industrial nations. That the
resource is now rationed free of charge strongly reinforces the
plausibility of the view that a "common heritage" resource is being
unjustly appropriated by the industrialized nations

An international leasing market would result in income redistri-
bution that might defuse the militance characterizing some LDC's
recently but not destroy the incentives of the industralized nations
to continue technological development improving resource utilization.

It would be naive to believe, given what has transpired in the
case of the first renewable space resource, that the U.S. would not
receive a great deal of political heat for exploiting nonrenewable
space resources, such as space minerals. Any future "space policy"
must be prepared to address this problem on at least the rhetorical
level, though it's not so far-fetched to imagine world politics
leading to the creation of an international authority to lease space
mineral rights [26].

The other question of interest only briefly discussed in the
body of the paper concerns how the channeling of research and devel-
opment funds is affected by the assessment of a resource's value.
Because there are not market prices for "orbit-spectrum," there is

a tendency to improperly compare different parts of the same
resource. For example, the 30/20 gigahertz band is not as
easily usable (hence valuable) as the 6/4 band. Yet, the two
are described as almost perfect substitutes in R&D discussions.
Proper valuation would give a better measure of the return on
both extensive and intensive development, and thereby a better
idea of where to spend public R&D moneys.

Notes

1. Rather arbitrarily defined as frequencies between 0 and 300 gigahertz (GHz). 1 gigahertz = 1 billion cycles per second.

2. The word "allocation" has two meanings in this paper. The usual meaning refers to the distribution of economic resources in general. The specific meaning refers to the process by which classes of services are allotted a region within the spectrum. It is hoped that which meaning is intended will be clear from the context.

3. Section 301 of the Communications Act of 1934 contains essentially the same language.

4. Ronald Coase argues that the Congress overreacted by passing the Radio Act of 1927, adopting a solution far more encompassing than avoidance of destructive interference required. He argues that the courts would have, in time, arrived at a workable definition of radiation rights optimizing the level of destructive interference even with no legislation at all. Coase, Ronald H., "The Federal Communications Commission," Journal of Law and Economics, II (Oct., 1959). Charles Jackson counters that the importance of interference-free radio communications to the safety of maritime operations (the primary user of radio spectrum in the early part of the century) and the then relative simplicity of an administrative solution (prior to an era when billions of dollars could hinge on the outcome of a decision, or for that matter, when spectrum was even noticeably scarce) makes the "press for government monopoly more understandable." Jackson, Charles L., "Technology for Spectrum Markets," PH.D. Dissertation, MIT, 1976.

5. Descriptions of the allocation and assignment process appear in Coase, op. cit., and Robinson, John O., "An Investigation of Economic Factors in F.C.C. Spectrum Management," F.C.C. Report No. SAS 76-01.

6. A discussion of this information overload problem appears in Robinson, Glen O., "F.C.C.: An Essay on Regulatory Watchdogs," Virginia Law Review, Vol. 64, 1978.

7. There are, of course, a number of nontrivial assumptions being made here about what constitutes "highest value" in a social sense. However, even when social value is somehow determined to differ from market price, there are still ways to employ market mechanisms, and their attendant information economies, to the distribution of resources. For a discussion of this problem see Schultz, Charles, The Public Use of Private Interest, Brookings Institution, Aug., 1977.

8. In fact, many view price systems as nothing more than a
    highly efficient information system serving to promote
    mutually beneficial transactions between parties.

9. Owen, Bruce M. "Spectrum Allocation: A Survey of Alterna-
    tive Methodologies," Office of Telecommunications Policy
    Staff Paper, April, 1972.

10. Coase, in a footnote on page 27 of his article (op. cit.
    note 4), remarks that his most fundamental complaint is
    that certain desirable market transactions are impossible
    under current law.

11. Henderson and Quandt, Microeconomic Theory, 2nd ed., p. 279,
    McGraw Hill, 1971.

12. Robinson, John O. "Introduction to Economic Factors into
    Spectrum Management," Masters Thesis, p. 28, Annenberg
    School of Communications, Univ. of Pennsylvania, 1974.

13. Note that opportunity cost minimization is not the same as
    accounting cost minimization. The latter is minimized by
    zero output whereas the former is not--idle resources have
    a positive opportunity cost.

14. Not that I am the first to address them--indeed, many have.
    However, no matter how many times they are addressed they
    crop up again and again.

15. As used here, "enforcement" includes both detection of a
    violation of somebody's rights, and adjudication for pur-
    poses of resolving disputes over rights or punishing
    offenders.

16. This crude model is designed only to illustrate a point.
    Note that it is not capable of handling the more likely situ-
    ation where A's violation of B's right is unintentional. The
    simple model could be extended by allowing A either to expend
    an amount e to be assured he is violating nobody's rights, or
    expend nothing and face probability q that he is violating
    somebody's rights. Letting b* be the state of the world in
    which A has expended e to be sure that no violations have
    occurred, the decision criterion becomes:

    $$U(b*) > (1-q)U(b) + q[(1-p)U(a) + pU(c)]$$

    If e depends on q in an appropriate way (i.e., q>0 then e>0
    and b*>b) and U(a)>U(b)>U(c), then there will always be a p
    between 0 and 1 such that for all probabilities greater than
    this p, A will expend e to guarantee that he is violating no-
    body's rights. If feelings of guilt accompany a violation
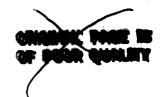
16. (continued)

of somebody else's rights then it may be that U(b)>U(a). If this were true for everybody in society, then, according to the simple model, no violations would occur, even if society spent nothing on detection (p=o). Thus, the social purpose of guilt may be largely that of keeping enforcement costs down.

As for the trade-off between detection probability and punishment, Gary Becker has noted that "a common generalization by persons with judicial experience is that a change in the probability has a greater effect on the number of offenses than a change in the punishment. . .," Becker, Gary S. "Crime and Punishment: An Economic Approach," Journal of Political Economy, pp. 169-217, March-April, 1968.

17. DeVany, Arthur S., Eckert, Ross D., Meyers, Charles J., O'Hara, Donald J., & Scott, Richard C. "A Property System for Market Allocation of the Electromagnetic-Spectrum: A Legal-Economic-Engineering Study," Stanford Law Review, XXI, pp. 1499-1561, June, 1969.

18. Dunn, Donald A., & Owen, Bruce M. "Policy Options in Mobile Radio Spectrum Management, Report to the F.C.C., Sept., 1978.

19. Reinhart, Edward E. "Orbit-Spectrum Sharing Between the Fixed-Satellite and Broaacasting-Satellite Services with Applications to 12 GHz Domestic Systems," NASA Report R-1463, p. 189, May, 1974.

20. For example, Reinhart's report, previously noted.

21. Jackson, Charles L. "Technology for Spectrum Markets," Ph.D. Thesis, p. 71 ff., MIT, 1976.

22. Ibid 21.

23. How negotiations of this kind might be effected is extensively described in the article by DeVany, Eckert, Meyers, O'Hara, and Scott, referred to in note 17.

24. Russell, S. P., & Lusignan, B. B. "A Techno-Economic Approach to U.S. Domestic Satellite Orbit-Spectrum Regulation," IEEE Compatibility, Vol. EMC-19, No. 3, p. 351, Aug., 1977.

25. This approach is discussed in detail by Jackson in "Technology for Spectrum Markets," op. cit. note 21.

26. For those to whom this seems too "far out," I would
     only point out that the same could have been said 100
     years ago about the idea that apportionment of deep
     seabed resources would someday become the politically
     heated issue it has in fact become in recent delibera-
     tions at the Third U.N. Conference on the Law of the
     Sea.

FREQUENCY COORDINATION AND SPECTRUM ECONOMICS

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September 1982

Abstract

Market-like techniques have been advocated as substitutes for direct
regulation of the radio spectrum. However, one of the most frequent
objections to such techniques is that they are technically unworkable
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technique of spectrum management: "frequency coordination." Although
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way to insure technically efficient spectrum use, we show how frequency
coordination institutionalizes an implicit economic market, with attendant
property rights, and thus promotes economically as well as technically
efficient spectrum use.

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FREQUENCY COORDINATION AND SPECTRUM ECONOMICS

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ABSTRACT

Market-like techniques have been advocated as substitutes for direct regulation of the radio spectrum. However, one of the most frequent objections to such techniques is that they are technically unworkable because of the complexities associated with assuring electromagnetic compatability between spectrum users. This paper reports on an existing technique of spectrum management: "frequency coordination." Although many spectrum managers see frequency coordination as merely a practical way to insure technically efficient spectrum use, we show how frequency coordination institutionalizes an implicit economic market, with attendant property rights, and thus promotes economically as well as technically efficient spectrum use.

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INTRODUCTION

It is striking how often professionals from different disciplines, while considering the same problem, emphasize different aspects of its solution. Such is the case, we believe, with formal frequency coordination procedures, particularly those used by the Fixed and Fixed-satellite services in the 4 and 6 GHz frequency bands. Most engineers see frequency coordination rules as a practical way of ensuring technically efficient spectrum use. In short, the rules are technologists' response to a technical problem.

The authors, however, see frequency coordination as an economic activity with some technical aspects. As we explain below, the rules of frequency coordination institutionalize an implicit market in "property rights." The cumulative effect of the frequency coordination process is to transfer these rights to the users who value them the most. This is an economically efficient outcome even though it is not achieved using a formal market arrangement, such as an auction. In short, although technical and economic efficiency are different concepts,[1] we believe frequency coordination promotes both. Indeed, as far as we know, it provides one of the few successful working examples of an economically efficient technique for spectrum management. As such, it deserves consideration when procedures must be devised for ensuring electromagnetic compatibility in new services.

Economic techniques for spectrum management are often thought to involve formally organized markets. In recent years auctions [2] "shadow prices" ([3][4][5]), markets of "output rights" [6], geostationary "orbital slots" [7], and other formal markets have been proposed. However, these

organized markets are not the only possible, useful spectrum management technique. Economically efficient use has much more to do with use than with markets. Loosely, economic efficiency means obtaining a good or service whose quality is acceptable to its users in a least-cost manner.[2] While formal markets can be shown theoretically to promote such use, less highly structured arrangements can also serve this purpose. In fact, the earliest proposals for economically efficient spectrum use [9],[10] envisioned markets operating more along the lines of frequency coordination than did later proposals.

From an economic standpoint, frequency coordination (as a requirement for the issuance of a construction permit and license) works because it provides everyone using it with incentives to use spectrum efficiently. Coordination's rules are based on the principle that existing users should be protected from harmful interference caused by later users. This principle effectively gives limited property rights in a portion of the spectrum to whomever uses it first in a given geographic area. These rights include permission to transmit a signal with specific technical characteristics from a particular point. Subsequent applicants for that portion of the spectrum must demonstrate to existing users that they will not cause interference above a specified level to any of them. Thus, coordination assigns the liability for harmful interference to new users, while simultaneously giving those users a mechanism for "coordinating" (i.e., discussing and amending as necessary) their plans with existing users. This combination of (1) well-defined liability rules with (2) simple procedures for identifying and resolving conflicts makes frequency coordination effective from an economic standpoint.

The principles just summarized need not be restricted to the 4 and 6 GHz frequency bands or to the Fixed and Fixed-satellite services. The ideas are transferable to other bands and services, and, in fact, recent proposals have been made to use these ideas in Multipoint Distribution Service (MDS) [11], and in FM broadcasting ([8], Chapter VI).

BACKGROUND

When communication satellites first became feasible, desirable frequencies for such systems were already allocated to point-to-point microwave relay systems operating in the Fixed service. These allocations were heavily used in many urban areas, and it was thought that little additional use could be made of them. However, it soon was discovered that the technical characteristics of the satellite and terrestrial services were sufficiently different to permit earth stations to be installed not only in parts of the country where there was little Fixed service operation, but even in congested areas where another radio-relay system could not be accommodated. Coordination procedures to facilitate the sharing of the bands by these services were first developed by the International Radio Consultative Committee (CCIR) of the ITU. These procedures were subsequently adopted internationally and are currently embodied in Appendix 28 of the Radio Regulations. These procedures have also been incorporated into the FCC Rules and Regulations ("Rules") with only a few changes in interference criteria and assumed system characeristics.

The Fixed-satellite service (FSS) shares the 500 MHz wide 4 and 6 GHz bands (among others) with the Fixed (terrestrial microwave) service. To

make such sharing possible, interference must be prevented between the two

services. Among the possible interference situations are signals from the

Fixed service (terrestrial station transmitters) to the Fixed-satellite

service (earth station receivers) and from earth station transmitters to

terrestrial station receivers.[3] These two interference cases, which are

subject to the rules for coordination provide a clear and interesting illus-

tration of the economic aspects of this technique and will be discussed

here.

International and Domestic Coordination Rules

As noted, interference between the earth stations of satellite systems

and fixed stations, and the associated requirement to coordinate the estab-

lishment of a new earth station or radio-relay station with other users, is

covered by Appendix 28 to the Radio Regulations. Appendix 28 gives a

"worst-case" method for calculating the so-called "coordination area" within

which harmful interference may occur. These calculations are based on

assumed characteristics for existing systems and the actual characteristics

of the proposed system. The Radio Regulations, which have treaty status,

then call for coordination (that is, discussion) between the operator of the

proposed new station (whether earth or terrestrial) and the operator(s) of

existing station(s) within the coordination area (whether terrestrial or

earth, respectively). However, this requirement does not set a specific

limit on how much interference a new station can cause—that is up to the

existing users in the coordination area.[4]

The FCC <u>Rules</u> (specifically, 47 CFR §25.203) contain the requirement for coordination. The procedures set forth in Appendix 28 are incorporated in Sections 25.251-254. The <u>Rules</u> also require coordination with the fixed (terrestrial) service (47 CFR §25.203(c)-(d)). The requirements for the Fixed service [47 CFR 21.100(d)] are typical:

> All applicants ... shall, before filing an application or major amendment, ... coordinate proposed frequency usage with existing users in the area and other applicants with previously filed applications, whose facilities could affect or be affected by the new proposal in terms of frequency interference or restricted ultimate system capacity.

Thus, in the U.S. an applicant for a construction permit must (a) determine if harmful interference may be caused to existing users, (b) inform those users potentially affected of his plans, and if possible (c) take whatever steps are needed to obtain these users' agreement to the proposed operation. Under point (b), every applicant must communicate the technical details of his proposed station to every existing user within the coordination area with whom calculations show the possibility of harmful interference, and obtain the concurrence of <u>all</u> such users in his plan. Following the successful coordination, and the grant of a construction permit by the FCC, the station is protected in turn.[5]

Effect of Coordination Calculations

Coordination distance calculations are, as noted, based on a number of worst-case assumptions, which depend on the frequencies involved and the state-of-the-art in the service, as well as an allowable incursion into the noise budget of a particular type of system. Given a particular level of

"permissible noise," appropriate propagation models are used to estimate the distance at which this interference could be caused. These distances define the boundary of the coordination area. For example, Appendix 28 and the associated Recommendations of the CCIR contain methods for calculating areas where harmful interference may occur by either great-circle propagation or by scattering from precipitation. The boundary of the coordination area is the union of the areas found by applying each of the two methods separately.

Because operators of systems outside the coordination area need not be consulted by a newcomer, the selection of a permissible noise level and of particular interference models determine both the level of protection afforded to existing systems and the number of systems with which a newcomer must deal before being licensed. The current rules are conservative in this respect; the worst case assumptions embodied in them mean that many or even most systems identified by coordination calculations will not, in fact, suffer harmful interference from the newcomer's operation. The actual coordination between service operators is intended to identify probable as opposed to possible interference. In the U.S. this is done through data bases of licenses, construction permits and pending applications which are maintained by independent companies and by certain of the common carriers who use the 4 and 6 GHz bands extensively. These data bases serve the same role that a data base of land titles serves in real estate--they economize on the cost of obtaining a clear "title" to the spectrum.

If a detailed examination shows that harmful interference may be caused, the newcomer has several alternatives.[6] Of course, the applicant could abandon the proposed site and seek another further away from

conflicting stations, or where the antenna pointing directions would be more favorable. Alternatively, other alternatives could be employed:

- Restricting the directions in which the earth station antenna might point (thereby limiting the orbital locations of satellites with which the station could communicate),

- Restricting the frequencies on which the station would operate (i.e., coordinate less than the full 500 MHz band, thereby limiting the total number of channels that could be carried by the station, and therefore both the maximum communication capacity of the station and the flexibility in assigning channels to and from the station and within the system it serves),

- Constructing artificial barriers to transmitted and/or received interference (e.g., pits, earthen embankments, and metallic shielding fences), or

- In certain cases, installing a more directional or better shielded antenna at the proposed and/or one or more <u>exist-ing</u> stations.

In fact, the last remedy is embodied in the FCC Rules (47 CFR §25.251(d)), which states that although a less discriminating, so-called "Standard B" antenna may be used in areas of low-traffic density, an exist-ing operator must install a better, "Standard A" antenna if this would eliminate the harmful interference. However, antennas even more discrim-inating than "Standard A" are available from several manufacturers at prices considerably higher than "Standard A."

In many cases, use of such antennas by a Fixed station would eliminate the possibility of interference between a new station (either a fixed terrestrial or a satellite earth station) and an existing one, but the installation of such antennas are not required under current FCC Rules. However, these super-directive antennas are sometimes installed with the newcomer voluntarily paying some or all of the cost even if the antenna is installed on an existing system. As we demonstrate below, such economically efficient and technically desirable solutions to an interference situation are to be expected in a market system.

PROPERTY RIGHTS AND COORDINATION

Having reviewed the operation of coordination, we now can use the economic theory of property rights to analyze coordination's effects.[8] The basic idea is simply stated: achieving economically efficient use involves finding an allocation of goods to users in which no further gains from trade are possible. However, before such an allocation can be found there must be well-defined goods, and it has to be possible to trade them. The rules of frequency coordination define a tradable good, i.e., the right to operate a system with known characteristics, free from harmful interference.

Although we refer in this paper to "spectrum," the property rights involved in coordination do not involve some abstract "invisible resource" [3], "ether," (suggested in [9]) or a right to use some "time-area-frequency" combination (as in [6]). The rights provided under coordination guarantee the reception at one or more receivers of the signal from a particular transmitter which is free from harmful interference. Harmful

interference can be prevented by any technically feasible means, including
separation of systems in space, time or frequency, but the means used are
not a part of the right. In short, an existing user has a right to a
"clear" communications channel.[9] This right must be respected by newcomers,
although the existing user is free to surrender all or part of it if this is
in his best interest. The trading of rights occurs when the characteristics
of one or both systems are modified. Since such trades are voluntary, only
those that leave at least one trader better off than without the trade will
be made. Each completed coordination thus moves one step toward more
efficient use of the spectrum.

An Example of the Economics of Frequency Coordination

To demonstate how coordination promotes efficient use, consider the
following example. Suppose the coordination calculations determine that
if an operator A builds a new earth station at some location, harmful inter-
ference will be caused to an existing Fixed system operated by B. Install-
ing a super-directive antenna on B's system to protect it from the interfer-
ence has a net cost of $100. However, if the interference is not reduced by
the antenna, A's earth station must be located at another site further from
its intended service area. The additional cost of using this location is
$200.

First, what is the economically efficient outcome? We assume, in doing
this, that costs to either A or B represent costs to society, i.e., the
value of resources diverted from some other use is $100 in one case and $200
in the other. If the antenna is installed, society is better off by $100

(the difference between the $200 cost saving for the earth station and the $100 cost of the antenna). Installing the antenna and allowing the new earth station to operate is therefore the economically efficient solution to this spectrum management problem. This solution also makes more intensive use of the spectrum in this area, so installing the station would probably be judged technically efficient as well. (Moreover, the performance of B's system will often be improved in other ways than interference rejection to A's signals: the new antenna typically increases the signal-to-noise ratio, or the margin against fading and, hence, increases system quality or availability.)

Under the coordination rules, A is liable for harmful interference caused to B's fixed system. When notified by A of the potential interference, it is in B's interest to refuse to allow A to operate unless compensated in some way by at least enough to pay for the installation of the antenna. That is, the compensation must be worth at least $100. Since this amount costs A less than the $200 required to relocate the earth station, it is in A's interest to make such compensation. For instance, A may offer to install the antenna at no cost to B. Notice that if both users act according to their self-interest the negotiations arising from coordination lead to the installation of the antenna, and the establishment of the new earth station--the economically (and technically) efficient solution will be achieved without regulatory intervention.

The efficient solution also will be chosen if A is the existing user of the spectrum, and B the newcomer. In this case, however, B will choose to

build his system from the first with the super-directive antenna, since pay-
ing the extra cost of $100 is less expensive than paying A at least $200 to
relocate his earth station.[10]

Coordination when Spectrum Use is Growing

Coordination also can achieve efficient use where business growth or
new technology lead to growing spectrum use. Assume that initially the
frequency allocation in the area is unused. Coordination is trivial for the
first user to establish a station. Indeed, it will probably be easy to
accommodate many early users in this relatively uncongested environment.
Transactions such as the antenna upgrading discussed above will rarely be
needed, because each newcomer will probably be able to locate his facilities
so as to avoid interference with any existing user.

However, as the available frequencies and sites are filled with users,
coordination will require adjustments to someone's system more and more
often. These adjustments will be of the kind reviewed above--antenna
upgrades, changes in transmitter or receiver design, and so forth. In each
case, users who follow their self-interest will adopt economically efficient
solutions to their electromagnetic compatibility problems. The cumulative
effect of the individual decisions will be to substitute technological
sophistication for spectrum use in a least-cost manner.

If growth continues long enough, the intensity of spectrum use will be
as great as can be accommodated by the state-of-the-art. Specifically, no
technical alternatives will exist that are worth installing. New systems
can enter only if existing systems cease to operate.

As far as we know, this state of affairs has not been reached. Although many urban areas are highly congested, the steady advance of communications technology has kept spectrum use from being completely constrained. But, even if saturation occurs, coordination would still promote efficiency. In this case, the new system's operator would have to be willing to pay enough to persuade the operator of some existing system to cease operation. This might be feasible, for example, if an alternative to radio transmission such as coaxial cables or optical fibers were available to some users at a cost below what the new operator was willing to pay. Thus, coordination encourages economic substitution between technologies that use spectrum and other information transmission media.

Effect of the First-Come, First-Served Principle

This discussion shows that the use of spectrum will be economically efficient, provided negotiations are possible at relatively low cost. However, the final distribution of wealth between the operators of the different systems is different depending on who is the existing user and who is the newcomer. In the example, B's fixed station is the earlier user, and A must pay B at least $100 to effect a coordination. If A's earth station is earlier, B would pay $100. In short, the first-come first-served principle transfers wealth from newcomers to established spectrum users.

The fact that the first-come first-served principle imposes the cost of any adjustments on newcomers is a central issue in the on-going international debate over "planning" orbit-spectrum use in the Broadcasting Satellite service in ITU Region 2, which includes the United States. The

above argument suggests that frequency coordination (an alternative to planning) would lead to efficient use of the available orbit-spectrum. However, the developing countries argue that this principle may impose an unfair hardship on them, since they are almost certainly going to be using the resource later than the developed countries. While this paper is not the place for a discussion of the debate over planning international orbit-spectrum, its seems to us that efficient use and wealth-transfer ought to be regarded as separate issues, amenable to separate solutions. In particular, if coordination is used to promote efficient use, some arrangement that reallocates some of the costs from newcomers to earlier users may be required in order to achieve equity.

Is There an Incentive to Prematurely Use Spectrum?

The first-come first-served rule may provide an incentive for claiming "rights" by building and coordinating a system before its use is otherwise justifiable. Obviously, an early entrant is entitled to be compensated by latecomers, and avoids the need to make such compensation. However, the size of the distorting incentive to premature use depends on the present value of the cost of expected future modifications (and associated compensation) to the early entrant system, since these costs are avoided by early entry. These costs avoided by early entry, however, do not seem to have been very large in satellite systems to date.

The argument is as follows. A potential early entrant has two choices. Early entry means that at some future time engineering changes will be required to his system. However, the costs of these changes will be

borne by latecomers. On the other hand, if construction of the system is delayed these changes may have to be incorporated from the start. However, the operator will have saved any capital and operating costs associated with the system during the time prior to its eventual use. The difference between the cost of these two alternatives measures the strength of the incentive to be an early entrant.

This cost difference will only be significant if (1) upgrades to an existing system are substantially less costly than changes to a proposed system, but (2) they are nevertheless very costly in comparison to the system's other costs. Our investigation ([8], Chapter V) indicates that neither condition holds very often. Upgrades are seldom substantially cheaper than design changes because continuing technological advances reduce costs. And, most cases of coordination involve incremental, relatively inexpensive changes such as antenna improvements. Therefore, it seems to us that the incentive to prematurely claim spectrum through coordination, although a theoretical possibility, is not practically important in systems built to date.

SOME PROBLEMS WITH COORDINATION

This is not to say, however, that coordination is without problems. It has them, although some can be ameliorated by changes in the existing rules.

Coordination over Time

One issue that needs to be addressed is the extent to which coordination leads to optimal decisions over time when there are so-called

"irreversible" investments. We illustrate this problem using the example introduced above, involving users A and B. Suppose that the first system introduced is B's fixed system. Since _t is the only system, it suffers from no interference. If B designs the system to be more resistant to interference than is initially required (e.g., using a super-directive antenna), the cost of this additional protection may not be very great. However, retro-fitting the system at a later date to give equivalent protection is more expensive because unanticipated changes must be made. Now, let A's earth station be the newcomer, with a $200 cost saving if it uses its most preferred site, which will cause harmful interference to B's system unless it is protected.

As discussed in [8], coordination may not choose the economically efficient outcome in this case. Whether it does so or not depends on:

1. How much more expensive retrofitting is compared to
    designing the protection into the system from the
    start,

2. The time lag between the start of B's operation and
    the entry of A, and

3. The interest rate applicable to B's investment.

Basically, examples can be constructed where the least costly alternative overall is for B to install protection from the beginning. However, B may have no incentive to do so. Obviously, a mechanism is needed which gives B an incentive to install extra protection at a time when his system does not need it.

There are several ways to provide this incentive. The FCC rule allowing fixed service operators to assert protection for systems up to five

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years in advance of their operation is one way to address this problem. For

example, if A's earth station were allowed five-year advance protection (and

if it were actually optimal to install it in less than five years), A would

be willing to compensate B to build in protection _ab_ _initio_. Alternatively,

if A's earth station were granted protection before B's was, B would build

in the extra protection in order to operate.

Limitations on Trading

Another problem with the present rules for coordination is that it

sometimes is difficult to transfer the implicit "rights." The problem,

related to one that arises in water rights law ([15], Ch. 2), is as follows.

Suppose an operator A has established rights through coordination. As

noted above, these rights are to interference-free use of a particular

communications channel. Whether or not A can transfer this right to another

party B depends on how B will use them. If A's and B's uses of spectrum

were identical (and if B's use were in fact the more valued of the two), B

could "buy" A's permission to operate, and A would cease operation. The

problem arises when B's use is not identical to A's. If B plans to create

less interference than A, he may not want all of A's implicit rights. The

problem is that A cannot always retain whatever portion of his rights B

doesn't acquire. For instance, A's rights lapse if he ceases operation at

the old location--hence, he cannot be compensated for them. As a result,

eamples can be constructed where A and B are not able to reach an agreement

[8].

Of course, other users in the area presumably suffer less interference when B replaces A. If transactions costs were truly zero, it would be possible for all the other users of spectrum to band together and buy those rights that B doesn't want. The coalition of other users benefits by the reduced interference, and A is compensated for his rights in this case. But transactions costs are not zero, and the formation of such coalitions may violate the antitrust laws. As a result, negotiation solely between A and B may fail to produce an efficient solution.

An attractive solution to this problem is similar to one proposed for water rights ([15], p. 35). Under it, A's rights could be transferred in their entirety to B, even though B didn't use all of them. B could coordinate his system in the future as if it were A's. This solution allows A and B to complete their transaction, and gives B an asset (the rights he isn't using) to dispose of during future coordinations. This possibility is not allowed by the existing rules.

How Much Protection is Reasonable?

A third problem is a technical one: the fact that there have been few, if any, proven cases of interference between operating satellite earth stations and fixed terrestrial stations [8] suggests that the interference criteria and/or propagation models used in coordination may be overprotective. The implication is that much greater use could be made of these frequencies with only a small increase in the likelihood of interference.

An analogy from another field may be helpful in illustrating this point: a criterion employed by bridge players is, "if you make every slam contract you bid, you're not bidding enough slams." If the interference

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criteria employed to date have resulted in substantially no interference
they probably are too restrictive. The increased use which could be made of
the spectrum through relaxed criteria could be so much more productive, and
profitable, that it would outweigh the occasional instances of interference
that might result. The solution to such interference is insurance: a tax
imposed on, or a trust-fund established by, all "interference-marginal"
newcomers (that is, applicants who do not meet the present interference
criteria) could compensate existing users for the occasional cases of inter-
ference that might result. (A fund established by all such users would be
needed, since it is often difficult, or impossible, to ascertain the source
of unintelligible interference received for very small percentages of time.)

EXTENDING COORDINATION TO OTHER SERVICES

We have already noted that coordination's costs are relatively small:
for example, independent coordination companies charge as little as $1500
for coordinating a simple receive-only early station [8]. But the prolif-
eration of small earth stations, and their attendent low cost, has made
coordination relatively expensive for some systems.

The FCC has responded to the proliferation of receive-only stations by
allowing such stations to operate without a license. However, unlicensed
stations receive no protection against harmful interference by newcomers.
We feel that it would be better to extend the principle of coordination to
receive-only stations by licensing them, and recording the characteristics
of the station, without requiring coordination. Operators of receive-only
systems would thus be afforded protection from later applicants for licenses

to operate a transmitter. Since their operation cannot interfere with any prior system, coordination calculations are unnecessary in any event.

The effect of such a rule on the current TVRO (television, receive-only) stations would be to give them the same incentives and opportunities available to other systems. For instance, they could not be arbitrarily interfered with by newcomers. Instead, newcomers would have to take the use of spectrum by receive-only stations into account, deferring to this whenever and wherever this is economically justified.

The incentives for efficient use provided by frequency coordination make it attractive in other services. For instance, there are a number of "one-to-many" services, such as the Multipoint Distribution Service (MDS) and the broadcasting services, where one transmitter sends to a large number of receivers. What is needed here is some way to give the operator of a transmitter protection from harmful interference in some service area around each transmitter. Such areas are sometimes called "protected service areas" by spectrum mangers (e.g., [11]). Methods of calculation exist (e.g., Close [17]) which allow realistic contours defining such areas to be drawn.

We believe that the rules for defining protected service areas should also do two things:

1. <u>Require</u> newcomers to demonstrate to existing users that their proposed operation will not generate interference that encroaches on the existing users' protection areas.

2. <u>Permit</u> existing users to allow a newcomer who may encroach on a protection area to operate, i.e., permit voluntary modification of an existing user's protection area.

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Such rules are a part of the FCC's technical proposals for MDS in Docket 80-113 [11]. In [8] we discuss a similar set of rules for FM broadcasting. Both [8] and [17] present calculations showing that substantial gains in the number of people served are possible if realistic protection areas are used and if technical trade-offs which alter these areas are made between existing users and newcomers.

CONCLUSION

The preceding sections have pointed out how frequency coordination defines a system of property rights, and thereby promotes spectrum efficiency. Despite the far from crippling problems just discussed, coordination in practice works reasonably well. As noted above, there are no known instances of interference in the United States, and as far as we know there has never been a case where the FCC has had to decide on a license application in which all coordination conflicts had not been resolved. In our earlier study [8] we summarized discussions with a number of members of the user community; none expressed a willingness to replace coordination with direct regulation by a government agency such as the FCC.

Coordination provides a lesson in how to promote efficient spectrum use that should be considered by other spectrum users. Basically, all that is required is a workable mechanism for determining which receivers and transmitters are likely to suffer from and cause harmful interference, combined with a clear statement as to which party is responsible for correcting any interference problem. Good information about the location and technical characteristics of stations also needs to be provided to users, but in most

cases, such information is available from radio license applications, or from domestic or international records on radio assignments.

We feel that frequency coordination has a role to play in efficient spectrum management that is too little recognized. If its key features are adopted more widely, we believe that all users of spectrum can benefit from the flexibility and efficiency that coordination provides.

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FOOTNOTES

[1] A number of articles in a recent special issue of the IEEE Transactions on Electromagnetic Compatibility [1] discuss this point.

[2] For a discussion of technical vs. economic efficiency, see [8], Chapter II.

[3] Typically a terrestrial station will operate in either the 4 or 6 GHz bands. On the other hand, a transmit/receive satellite earth station must use both bands and will therefore need to coordinate, and be licensed for operation in both 4 and 6 GHz.

[4] While CCIR Recommendations 356 and 357 recommend an aggregate limit for this interference, they provide no guidance as to the allowable contribution to overall interference by a single system.

[5] The FCC allows operators of receive-only earth stations in the Fixed-satellite service to elect to operate without coordination. However, any stations operated in this way do not receive protection from interference.

[6] No specific procedures are stipulated in the Radio Regulations (or the FCC Rules for that matter) and administrations (i.e., governments) are thus free to use any mutually agreed method for resolving the conflict.

[7] In addition to the alternatives cited, electronic sidelobe interference cancellers may become practical in the future.

[8] Interestingly, research on the economic theory of property rights has had a considerable rebirth in the last 20 years, due in no small part to Ronald Coase's study of spectrum management. His paper "The Problem of Social Cost [12] appeared only a year after his study of the FCC [9] which proposed a market in spectrum as an alternative to regulation. Coase's work on property rights stimulated others. In particular, there are Demsetz [13], Mishan [14], and Posner [15], whose chapter on the property law provides probably the clearest summary of the economic issues.

[9] [16] pp. 6-11 discuss this kind of right in greater detail.

[10] It can also be shown that coordination achieves the economically efficient solution if the numbers are reversed (i.e., if the antenna cost is $200 and the cost saving associated with the earth station's location is only $100). In this case the economically efficient solution is for the earth station not to operate at its most preferred location. Under coordination, the earth station operator (A) is willing to pay only $100, but the fixed system's operator (B) demands at least $200 to modify his system. Clearly, no transaction will take place, and the earth station will be located elsewhere in order to minimize costs. If B is the newcomer, on the other hand, he will be able to pay at least $100 to relocate A's earth station.

ALTERNATIVE LICENSING ARRANGEMENTS AND SPECTRUM ECONOMICS:
THE CASE OF MULTIPOINT DISTRIBUTION SERVICE

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Abstract

At present, the Federal Communications Commission assigns radio
licenses after making a determination of the public interest. Whenever
mutually conflicting license applications are filed, the Commission holds
a comparative hearing. This assignment mechanism has been criticized as
cumbersome and unreliable, and several alternative mechanisms have been
proposed. This paper analyzes three of these: (1) increasing the avail-
able spectrum, and (2) an auction or (3) lottery of radio licenses. The
analysis deals specifically with the Multipoint Distribution Service
(MDS). Although MDS is a relatively minor radio service, many other
services use the same assignment mechanism. The way in which the initial
batch of MDS licenses was assigned provides a unique opportunity for
empirical work on the economics of the licensing process.

The analysis suggests that the present system is indeed a costly way
to select applicants. Increasing the spectrum allocation by an amount
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ALTERNATIVE LICEN3TNG ARRANGEMENTS AND
SPECTRUm ECONOMICS:
THE CASE OF MULTIPOINT DISTRIBUTION SERVICE

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Alternative Licensing Arrangements and

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The Case of Multipoint Distribution Service

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ABSTRACT

At present, the Federal Communications Commission assigns radio licenses after making a determination of the public interest. Whenever mutually conflicting license applications are filed, the Commission holds a comparative hearing. This assignment mechanism has been criticized as cumbersome and unreliable, and several alternative mechanisms have been proposed. This paper analyzes three of these: (1) increasing the available spectrum, and (2) an auction or (3) lottery of radio licenses. The analysis deals specifically with the Multipoint Distribution Service (MDS). Although MDS is a relatively minor radio service, many other services use the same assignment mechanism. The way in which the initial batch of MDS licenses was assigned provides a unique opportunity for empirical work on the economics of the licensing process.

The analysis suggests that the present system is indeed a costly way to select applicants. Increasing the spectrum allocation by an amount sufficient to eliminate hearings will create more assignments than will be demanded by MDS in many areas of the country, which is wasteful if other uses are foreclosed. Rough calculations suggest that auctions offer a more efficient selection mechanism. Lotteries with resale of the license are also somewhat better than hearings, but not as good as auctions.

1. **INTRODUCTION AND SUMMARY** .

When government controls a scarce resource, and licenses private
individuals to use it, it must decide how to assign the license. This
paper presents an economic analysis of the method used in the United
States to assign one such resource: the radio frequency spectrum. The
current procedure is to license individuals to use a particular frequency
assignment following a comparative hearing to determine which of several
competing applicants will best be able to serve the "public interest."
Two alternative assignment mechanisms, recently under discussion, also are
analyzed: auctions and lotteries of licenses. A third alternative—
avoiding the problems of the present system by allocating enough spectrum
to eliminate competing applications—also is considered.

The debate over these alternatives began several years ago when
the FCC proposed changes in the Multipoint Distribution Service (MDS).[1]
Because of this, and also because there is some data available from the
period 1975-76 relevant to the demand for MDS licenses, this paper
analyzes the assignment alternatives as they might be applied to MDS.
Although MDS is a relatively minor service, the problems associated with
the present assignment system occur in other new services. In particular,
at the time of writing, the assignment of licenses for many mobile radio
services (including cellular), low power television and digital electronic
message service are being delayed by the requirement for comparative
hearings.

Studying how these alternatives would work in MDS is relevant to
these other services because the analysis suggests that auctions would
promote efficiency better than the existing system. Lotteries, with
resale of licenses permitted, also appear superior to the existing system,

but are not as good as auctions. The reason auctions promote efficiency
is that existing system encourages applicants to compete for the economic
rents associated with a license, and this competition wastes resoures.
There is much less of this kind of competition in an auction because the
winner must pay what is bid. Rough calculations presented below suggest
that the present system is three or four times as expensive as the
auction, with no offsetting benefits. Since similar competitive incen-
tives operate in other radio services, it seems likely that auctions would
be superior there as well.

The alternative of increasing the spectrum allocated to a service
like MDS cannot be compared easily to the other alternatives, because
there is no data that allows us to measure the cost of denying some other
service access to the additional spectrum to be made available to MDS.
However, for MDS at least this alternative appears unattactive. We pre-
sent evidence that the demand for assignments (at a zero price) is very
large in a few places, and fairly small elsewhere. If, as is currently
proposed, the spectrum would be allocated uniformly throughout the
country, it turns out that even the largest reallocation proposed would be
inadequate to satisfy the demand for assignments (at zero price) in a few
of the largest cities. However, such a reallocation would leave most of
the assignments idle over most of the rest of the USA. Unless the cost of
restricting the use of this idle spectrum by other services is very low,
uniform reallocation appears to be a wasteful solution.

The structure of the paper is as follows. Section 2 presents back-
ground on MDS, summarizes the historical development of the service, and
discusses the use of comparative hearings to award radio licenses. Sec-
tion 3 discusses the proposed alternatives to comparative hearings in

MDS. In order to compare these alternative policies one needs to know the value to society of the assignment. However, there is no market to provide a price for MDS assignments. Hence, Section 4 addresses the question of whether or not the value of an assignment can be inferred from other data. Specifically, the first part of this section presents a theoretical analysis of the hearing as a competitive process. This analysis suggests that the number of applicants will be proportional to the value of an assignment. A simple econometric model presented in the second half of Section 4 supports the theory by showing that the independent variables that should affect a license's value affect the number of applicants similarly. Section 5 then presents a comparison of the hearing, lottery and auction alternatives along with an independent analysis showing (along the lines discussed above) that increasing the spectrum allocation is likely to be inefficient. The paper concludes with a brief summary in Section 6.

2.   AN OVERVIEW OF MDS

Multipoint distribution service is a relatively new common carrier service used for broadcasting of multiply-addressed material to different fixed receivers.[2] In the top fifty television markets, MDS has been allocated two 6-MHz channels in the frequency band 2150-2162 MHz. (A 6-MHz bandwidth is the standard one for a television signal.) In other markets a single 6-MHz channel is allocated, along with a 4-MHz channel.

2.1 History

The rules for the present MDS service were established in 1972 with one 6-MHz channel (channel 1), and in 1974 the second 6-MHz channel (channel 2) was allocated in the top 50 television markets.[3] The Commission's decision in the 1974 case fixed MDS in its present form, and initiated its growth period. Table 1 shows the number of licenses and construction permits for channels 1 and 2 issued since that time. The compound annual growth rate for licenses shown in the table is about 41 percent.

MDS was initially used to distribute pay television programs to cable television systems, hotels, apartment complexes and the like. Consequently, the 4-MHz channel, which cannot carry a standard television signal, has been very little used. The growth shown in the table is entirely in the 6-MHz assignments. More recently, MDS has been used to distribute information services to businesses and households.

Immediately following the FCC's 1974 decision on MDS, a large number of license applications were filed. Because the number of licenses available was so restricted, many of these applications conflicted. That is, licensing one applicant necessarily prevented the Commission from

Table 1

Growth of MDS Licenses and Permits*

Time Period	No. of Licenses	No. of Permits
1974/5	7	18
1976	13	61
1977	22	74
1978	٤.	100
1979	54	66
1980	75	65
1981	93	129

* Excludes two users of the 4-MHz Channel 2A

Source: Television Factbook, for the years noted

licensing other applicants. Table 2 shows the multiple application situation in late 1975, about a year after the FCC's decision. The table shows the frequency with which different numbers of competing applications were filed for the same assignment. Under the rules then in effect (see below), a comparative hearing was required whenever there were two or more conflicting applications. As discussed in Section 4, the behavior of applicants in these competitive situations reveals information about the demand for licenses. By September 1975 the Television Factbook indicated a need for 127 hearings, 100 of which are for assignments in the top fifty television markets. That is, mutually exclusive applications were filed for every available assignment in the largest markets.

The multiple application situation was stable between 1976 and 1978—settlements among contending applicants roughly equaled new conflicting applications so that the backlog of unresolved conflicts was constant. Beginning in June 1978, a large number of new conflicting applications for channel 1 assignments were filed.[4] By mid-1980, the FCC reported that only 2 licenses had been authorized for channel 2, with 185 applications pending. All these applications were mutually exclusive, as were 131 of the channel 1 applications.

2.2 Legal Background on Assignment by Comparative Hearing

Sec   on 309(a) of the Communications Act of 1934 requires the Commission to award a license if it determines that the public interest, convenience and necessity will be served by so-doing. Section 309(e) of the Act states that if the Commission cannot make such a finding the applicant is entitled to a hearing.

Table 2

Number of Applicants for MDS Licenses

(September 1975)

Number Applications For An Assignment	Frequency of Occurrence / Applications for Each Channel
1	21
2	49
3	35
4	20
5	9
6	4
7	7
8	3

Source: Television Factbook, Vol. 45 (1976)

In 1945 the Supreme Court decided a case involving mutually exclusive applications for a broadcast license. In Ashbacker Radio Co. v FCC, 326 U.S. 327 (1945), the court held that when there are mutually exclusive applications, granting one without hearings on all deprives the losing applicant of its opportunity for a hearing. T.e Court ruled that it was not sufficient to set a hearing on the losing applicant's application after awarding the license, because this would place on the loser the additional burden of showing that the competitor's license should be denied, as well as showing that it is in the public interest to grant the loser's own application (326 U.S. 331).

The Commission's reaction to Ashbacker has been to hold a simultaneous hearing on all competing applications whenever they are mutually exclusive.[5] In the case of MDS, the initial case (Peabody Answering Telephone Service, 55 FCC 2d 626 (1975)) established five factors on which evidence was to be taken. The applicants were awarded "preferences" based on evidence on each of these factors, with the overall award made on the basis of these preferences.

While no general conclusions are possible from the few cases which have been decided, the Commission has indicated that there is often no difference between the applicants.[6] That is, many applicants often are technically and financially capable of providing the service, and can demonstrate to the Commission that providing the service would promote the public interest, convenience or necessity. Thus, the Commission probably could find in favor of more than one of the applicants if there were no conflict.

3.   <u>ALTERNATIVES TO COMPARATIVE HEARINGS</u>

In 1980 the FCC began to consider alternatives to hearings in MDS, opening three dockets on various questions, two of which are relevant to the hearing problem. At the time of writing, both these dockets remain open.

General Docket 80-112 proposes a reallocation of spectrum which would combine the existing MDS allocation with the allocations for the Private Operational Fixed (Microwave) Service (POFS) and the Instructional Television Fixed Service (ITFS). The reallocation would create a total of 33 television bandwidth channels for the three services. MDS would have a total of twelve channels as its "primary" allocation (i.e., MDS applications would have priority in these channels). IFTS and POFS would have primary allocations of eleven and ten channels respectively. If all primary channels in a given service area are occupied but one of the other 21 channels is available, an MDS station could be licensed to use one of the latter channels.

If adopted, this proposal will provide at least six times as many channels to MDS than now are available. (Because of adjacent channel interference, all the new channels may not be usable in a given service area. Hence, the exact size of the increase varies from one location to another.) Multiple application cases could be settled by assigning additional unused channels in the primary allocations of either ITFS or POFS.

The second proceeding is Common Carrier Docket 80-116, a notice of inquiry and proposed rulemaking into methods for awarding licenses. The Commission, noting that "our recent experience reveals a trend toward fewer and fewer differences ... (between applicants)," and that "in the

near future we may find ourselves in a position where no differences exist at all or where such differences cannot be rationally measured against a public interest standard ..."[7] requested comments on the use of a lottery or an auction to select a licensee.

Under the lottery, a random drawing would take place among all "qualified" applicants--that is, applicants meeting some prespecified criteria. The present rules for MDS essentially require qualification on financial, technical and legal grounds. The basic lottery proposal analyzed in this paper assumes that a qualified applicant in a multiple application situation would be anyone whose application would have been granted in the absence of a mutually conflicting application.

In 1982, Congress amended the Communications Act to permit the FCC to use a lottery to award licenses, and the Commission has proposed a similar set of rules in other radio services.[8] In general the proposed rules do not require applicants to meet higher standards when there is a conflict that when there is not. However, the rules provide for a "preference" in the lottery for minority ownership or diversity in the television services affected. We assume below that all applicants have an equal chance in an MDS lottery.

Both the present and proposed rules would restrict the resale of licenses awarded by lottery. The so-called "anti-trafficking" provisions require an initial licensee to wait at least one year before transferring the license. The potential importance of a resale market is discussed in Section 5.

The auction proposal is an outgrowth of a plan suggested by Robinson (1978). The plan discussed by the Commission provides for would auction assignments to applicants, subject again to qualification standards which we assume to be the same as those for the lottery.

The actual auction could be conducted in several ways. From the viewpoint of economic efficiency, the so-called "English" or second price auction has much to recommend it. Under the sealed-bid version of this scheme the highest bidder wins, but pays the second highest price bid. Vickery (1961) and others[9] have analyzed this arrangement, and have shown that it has several valuable properties. For example, it causes every bidder to state his estimate of the true value of the object of the auction, given that he wins. (Stated formally, bidding the true estimate is a dominant equilibrium strategy for each participant in the auction.) As a consequence, the second-price auction should award the object to the bidder who values it the most. Also, it is relatively easy to determine one's bidding strategy, so that the costs of deciding how to bid are minimized. The auction system has the additional, not inconsequential, advantage of revealing the value of particular spectrum, through the bidding mechanism. This information can be used to make decisions about how much additional spectrum ought to be allocated to a particular service.

The analysis in this paper assumes that a second price auction is used. Under either the lottery or auction, licenses would be issued on the same technical grounds currently specified in the FCC's rules, eliminating the need to resolve interference. The license could run for the statutory term, and would be reauctioned at its expiration. (To facilitate reallocation of spectrum, all licenses in a given region should expire together.) The license's price would be a lump sum paid to the FCC. Transfer of the license would be allowed to any other party meeting the qualifications of a license holder, subject to the anti-trafficking rules mentioned above.

4.   THE APPLICATION DECISION AND COMPARATIVE HEARINGS

In Section 2 we saw that after the FCC's 1974 decision multiple

applications were received for all 100 assignments in the top 50 televi-

sion markets, and for many of the single assignments available elsewhere.

Because these applications were filed more or less simultaneously, they

provide information on the demand for licenses under the present system.

The data on these applications is important because of the simultaneity

(which is not present later in the history of MDS) and because it is

difficult to obtain similar data for newer services. On the other hand,

licenses in services such as radio and television broadcasting are bought

and sold after they are issued. Levin (1964, 1971, 1980), Crandall

(1977), Noll, Peck and McGowan (1972), and others have used this data to

analyze the economic behavior of these license markets, and the analysis

here follows the econometric specifications used in these studies.

There are two crucial points about the present system of assignment

that explain the pattern of multiple applications. First, the license

awarded to the winning applicant provides a limited, legal monopoly from

which the licensee can obtain an economic rent. The value of this rent

depends on several factors, including:

1.   The amount of competition from substitute services,

2.   The competition from other MDS licensees with overlapping
      assignments.

3.   Characteristics of the area being served, such as the number of
      households in the service area.

The second point is that the hearing is a competitive process with

both uncertain and significant participation costs. Moreover, applicants

appear to believe that their chances of success are improved by extensive

participation.

This section presents a model of this competitive equilibrium, supported with empirical evidence. The model is based on the idea that, if the applicants in any market are more or less evenly matched, the effort they devote to participating in a hearing (and the associated cost) will be proportional to the value of the rents associated with the assignment and inversely proportional to the number of competing applicants. It will follow that in an equilibrium with free entry the number of applicants will be proportional to the value of the license.

4.1 Model Structure

Since we are interested in the relationship beween the value of a licence and the number of competitors, the model described below concentrates on symmetric equilibria reached by identical license applicants. Obviously, this focus on symmetry is a simplification; there may be non-symmetric equilibria even if the applicants are identical, and in any case the applicants are not identical in practice. However, the symmetric case is convenient to work with and captures the essential features of the comparative hearing "game." More elaborate modeling is rather pointless in this case, because the data used in Section 4.2 do not allow us to say much about observable differences among applicants.

Specifically, we consider a symmetric Nash equilibrium, with expenditures taken as the strategic variable selected by each applicant. This equilibrium concept was chosen to capture the non-cooperative nature of the hearing process. While the Nash equilibrium may not be entirely realistic, it captures the nature of the competition among the applicants better than other possibilities. Moreover, given the form used here (essentially, a "local" equilibrium found by means of calculus), the solution is easy to calculate.

Consider a particular MDS market, and let V denote the value of the assignment when it is awarded to one of the applicants. V can be thought of as the certain equivalent of the present value of the future stream of profits derived by exploiting the assignment. (By the symmetry assumption, all the potential applicants have identical assessments of V.)

Under the present rules, each of the applicants $i = 1,\ldots,n$ will compete in a hearing for the license, provided n is at least two. We will assume that each participant assigns a probability $\pi_i(x_1,\ldots,x_i,$ $\ldots,x_n) = \pi_i(x_i,\underline{x}_{-i})$ to winning the license, where x_i is the i-th applicant's expenditure on representation and $\underline{x}_{-i}$ is a vector of the other applicants' expenditures. We have more to say about the form of π_i below.

Each applicant attempts to maximize the expected net value of the assignment:

$$S_i = \pi_i V - x_i \tag{4.1}$$

by choosing a level of expenditure $x_i^* = x^*$. We consider each applicant to know the other applicants' expenditures and seek a symmetric Nash equilibrium in the x_i^*'s.[10]

The function π_i , embodies an applicant's model of the hearing process. We will assume that each participant adopts the same "random utility" model of the selection process. Specifically, we assume that every participant thinks that the hearing officer associates a "utility" with an applicant's case of:

$$U_i = f(x_i) + e_i \tag{4.2}$$

where x_i is expenditure on participation, $f(x_i)$ is a function giving the contribution of expenditure to utility and the random variable e_i is identically and independently distributed according to the extreme value or Weibull distribution representing intrinsic differences between the applicants. As shown by McFadden (1973), if the hearing officer selects the applicant with the highest U_i, the probability that the i-th applicant receives the license is:

$$\pi_i = \left(\exp(f(x_i))/\sum_j \exp(f(x_j)) \right) \tag{4.3}$$

McFadden (1976) applied this choice model to the decision of a regulatory body.

With this specification for π_i a symmetric equilibrium can be found by maximizing Equation (4.1) with respect to x_i. It can be shown that the equilibrium expenditure x^* satisfies:

$$\frac{n-1}{n^2} \; V \; f'(x^*) = 1 \tag{4.4}$$

Since all applicants have the same x^*, Equation (4.3) implies $\pi_i = 1/n$ for all i. Consequently, the expected value of each applicant's rent is $S^* = V/n - x^*$. If entry occurs until this expected value is zero, the equilibrium $n = n^*$ can be found as:

$$n^* = V/x^* \tag{4.5}$$

Equation (4.5) provides the desired link between an observed quantity, the number of applicants, and the unobservable value of the assignment V. It forms the basis of our empirical work, which seeks to explain how variations in n^* (i.e., variations in V) are affected by the characteristics of the MDS market and by competition.

Since Equation (4.5) is derived from a model of symmetric equilibria, how robust is the proportionality between n* and V when the model's assumptions are relaxed? Rogerson (1982) shows, using a specialized version of the random utility model, that if there are differences in the abilities of firms to compete for a license, then the firms with an advantage in the competition earn positive expected piofits. However, even in this model the aggregate expected profits of all the competitors are proportional to the rents associated with the assignment (see Rogerson, Eq. 27).

Common sense suggests, however, that the proportionality relationship will not hold exactly—i.e., n* "measures" V with error. These measurement errors can be systematic or random. Systematic differences of this type can be accommodated in a regression equation. Random errors contribute to the regression error, and reduce the ability of the regression to account for all the variance in the dependent variable. Further discussion of possible systematic and random errors is presented below.

4.2 Data Used to Estimate the Model

The Television Factbook tabulates MDS licenses, construction permits and application activities since 1975, and so can be used to find the number of applicants n* . In addition, one systematic difference that may affect applicants' assessments of V is the previous award of a license for one MDS channel in a market. Such an award should convey information to the applicants for the second license about their pros-- pects. This suggests that for channel 2 applications, one of the independent variables affecting V would be whether or not a channel 1

application had already been awarded, or whether it was still t be

awarded. This variable was also derived from the Factbook.

Equation (4.5) predicts that variations in V will be reflected in

changes in the number of applicants n* . However, because V is an

economic rent, the availability of a competing assignment will affect the

license's value. If N is the number of available assignments, we expect

V to be a decreasing function of N. (Econometrically, N can be

treated as exogeneous since it is fixed by regulation for the period when

licenses are being awarded.) Data on N also can be obtained from the

Television Factbook.

The studies of broadcasting services cited above suggest that V

also will be affected by the size of the market served by the station. In

general, larger markets should be more valuable than smaller ones. The

market size variable used in this study is the Arbitron figure for ADI

(area of dominant influence) television households for the television mar-

ket that contains the proposed service area. This variable has several

unsatisfactory features. First, it is available only for large markets.

Consequently, the regression equation below may not hold for small

markets. Second, ADI households measures the potential audience in a

larger geographic area than an MDS station can serve. Data on a more

detailed geographic basis could not be obtained.

Systematic factors affecting the equilibrium in Equation (4.5) must

now be considered. In particular, several large multiple system operators

(MSO's) participated in certain hearings but not others. It might be

argued that if one or more of these MSO's participated, other applicants

would be inhibited from entry. We can test for this possibility by intro-

ducing indicator variables when an MSO participated.[11]

It also should be pointed out that there are two forms of truncation error involved with the data obtained in the Factbook. First, the model treats n* as if it were a real number, whereas in practice it is an integer.   Second, the Factbook never contains information on towns where there are no applications, so a form of selection bias is present.   Both these problems could, in principle, be addressed by additional modeling of the selection factors, coupled with the use of maximum likelihood estimation in place of ordinary lease squares.[12]

4.3 Regression Results

Table 3 shows the results of ordinary least squares estimates of the relation for n* . Overall, they support the equilibrium model developed in Section 4.1. The left-most equation is estimated for the 106 cases in which there were at least two applications. The specification is the same form as that used by Levin (1964, 1971), in which the value of an assignment was known from market data. As can be seen, the market size variable (log of ADI households) and the presence of an already licensed channel 1 are both highly significant. The number of assignments variable (N) has the expected sign, but has a T-value of only -1.8. Since this variable takes on only two values (one or two) there is probably not enough variation to give a significant result.

Basically, this regression equation (and the other two that are discussed below) represent the demand for an MDS assignment at zero price. Since a license is an input to the licensee's production of a service, the equation is a factor demand function, and the market size variable is a proxy for the output of the service to be provided by the

Table 3

ESTIMATED COEFFICIENTS*

Variable	(Dependent Variable is APPLICATIONS)		
Intercept	-3.911 (0.997)	-3.650 (0.954)	-3.404 (0.931)
Ln (ADI households)	1.322 (0.208)	1.270 (0.198)	1.223 (0.193)
Number of Assignments Available	-0.588 (0.329)	-0.560 (0.311)	-0.658 (0.355)
Channel 1 already licensed?	1.279 (0.285)	1.313 (0.275)	1.171 (0.273)
Single Application?		-1.432 (0.385)	-1.322 (0.379)
Largest MSO was an Applicant?			-0.0264 (0.363)
Other three top MSO's were applicants?			0.675 (0.317)
Standard error of estimate	1.091	1.061	1.027
$\overline{R}^2$	0.560	0.620	0.644
Number of Cases	106	115	115

* Standard errors in parentheses.

licensee. The number of assignments variable reflects the effect on demand of the availability of a substitute input while, as noted above, the indicator variable for channel 1 licenses may reflect a perceived difference between MDS markets with a channel 1 operating and markets where one is not yet operating.

The two right-hand columns show the effect of introducing additional variables, with the nine single-applicant stations included. The middle column simply shows results when these stations are included, along with an indicator variable for single applicant cases. This variable was significant, but the other regression coefficients were little changed. The right-most column contains two additional indicator variables for the presence of the largest MSO, or the second through fourth largest MSO, in a hearing. (Two variables were included because the largest MSO, according to industry sources, planned to operate a business communications network. Consequently, its actions in applying for licenses in different markets might have been motivated by networking considerations.) As can be seen, one of the two coefficients is significant but positive while the other is not significantly different from zero. The hypothesis that both coefficients are zero cannot be rejected at the 5% level $(F_{2,107} = 1.97)$, and none of the other coefficients are changed very much. The incorrect sign, and the lack of significance, suggest that this form of asymmetry, was not important in determining the number of applicants. Rejecting this specification has led us to use the center column in Table 3 for the work described in the next section.

5. ECONOMIC ANALYSIS OF ALTERNATIVE POLICIES

We now turn to a comparison of the hearing with an auction or lottery. The model of Section 4.1 showed us why the private value of the assignment and the number of applicants should be proportional to each other. It will be argued here that the private value approximately measures the value of the assignment to society. This allows us to make statements about the social costs and benefits of alternative policies using the model, and certain other information introduced below.

By social value we mean the sum of the (appropriately discounted) consumers' and producers' surplus associated with having an MDS station in operation, compared to the sum associated with the next best alternative.[13] However, the value of the assignment (V , in the terminology of Section 4) is an economic rent, i.e., the total (discounted) producers' surplus, associated with operating an MDS station as opposed to not operating one. In what sense does the latter of these quantities help us measure the former?

As noted in Section 4, the MDS operator's license awards a monopoly, or half of a duopoly. The operator's profits will thus include as producer's surplus a part, possibly a considerable part, of the consumers' surplus. In broadcasting, these profits are observable when a station is sold, and a number of studies (e.g., Levin 1964, 1971; Crandall 1978; and Webbink 1977) indicate that the market value of a station is many times its physical replacement cost.

While MDS is not a broadcast service, it does provide a one-to-many service. Indeed, since the operator may offer a multi-part tariff there are possibilities for discriminatory pricing not present in broadcasting.

This suggests that an MDS operator is able to extract a significant part
of the consumers' surplus associated with the service.

Moreover, operating an MDS station during the period to which the
data in Section 4 applies was essentially an all or nothing proposition,
so that the operator had no incentive to restrict output, resulting in a
welfare loss. This is because, during this period, MDS was primarily a
transmission service for pay television service during prime time. There
was essentially no demand for service outside of pr.me time. Faced with
what was in effect a sharply kinked demand curve, and having negligible
marginal costs, a profit maximizing MDS operator operated during prime
time and shut down otherwise. This is basically the efficient strategy.

So far we have given reasons why the economic rent might be close to
but lower than the social value. However, the rent is determined by the
FCC's rules, which do not allow any other use for the frequency assignment
if it is not used by an MDS station. This policy is not necessarily
socially optimal, because the FCC's rules prohibit alternative uses (e.g.,
transmission of instructional programming during daytime hours) that might
have a social value in excess of their transmission costs. Thus, the
value of an assignment may overstate the social value.[14]

The argument above may be summarized as follows. Ignoring issues
such as discounting, the social value of the present policy would be
measured by $W = (CS_{MDS} + PS_{MDS}) - (CS_{NBU} + PS_{NBU})$ where CS stands for
for consumers' surplus and PS for producer's surplus, and the subscripts
MDS and NBU stand for the present situation and "next best use." The
value of the assignment is $V = PS_{MDS} - PS_0$, where PS_0 represents the

producer's surplus in some other activity, with the MDS assignment idle.
The arguments that the licensee can appropriate much of the consumers'
surplus imply that CS_{MDS} is small compared to V. The FCC's restric-
tions mean that $PS_{NBU} \geq PS_0$. Consequently, $W \leq (CS_{MDS} - CS_{NBU}) + V$,
where the first term may be either positive or negative depending on the
demand for the alternative service and the monopoly power of that ser-
vice's provider, which determine CS_{NBU}. In what follows we take W
to be approximately equal to V, recognizing that in doing so we may
overstate or understate the result. We now turn to estimating V as best
we can.

5.1 The Value of an MDS License

If we had external observations on average spending on hearings x^*,
we could use one of the regression relationships and the fact that
$V \sim n^*x^*$ to estimate the value of the license. Unfortunately, only
anecdotal evidence is available. Robinson (1976) estimated the costs of
presenting an MDS case at 15,000 to 35,000 dollars per participant, based
on "rather sparse" information. Discussions with industry sources indi-
cate that this value was approximately correct at the time of writing,
when inflation is adjusted for.

This estimate of hearing expense implies that the typical comparative
hearing in 1975, with 3 applicants (see Table 2), involved a license
valued at between \$45,000 and \$105,000 (3 × 15,000 = 45,000, and
3 × 35,000 = 105,000). This estimate of the implied value of an MDS
license in 1975 obviously is only approximate, and therefore we may think
of the value of a "typical" station as being about \$75,000.[15]

5.2 The Costs of the Present System

Equation (4.5) suggests that private costs typically will equal the license's value of about $75,000. However, much of this cost is a transfer because it is paid by potential licensees to their lawyers, consultants and other experts on matters of interest to the FCC.[16] However, these costs can also represent real costs to society if they divert resources from other valuable uses. Moreover, we will see that they can be significantly altered under the other alternatives.

In addition to the private costs there are two additional categories of cost:

1. The administrative costs of the hearing to the spectrum manager (i.e., the FCC), and

2. The opportunity cost of the spectrum, incurred because the delay in the hearing process leaves the allocation lying idle or underused.

Robinson (1978) estimated that at least two months of FCC staff time were required, plus $1,900 in recording costs at the hearing itself. Using $60,000 as the cost of a year of staff time in 1975, including an allowance for overhead, this estimate implies a cost of about $12,000 per hearing.

However, Robinson reports that many of the conflicts are settled before a hearing. Of the first group, only 4 out of 74 had a hearing. If we assume that half of the staff time is needed in any case, and use the data given above, we find that the average administrative cost is about $5,400 (the average of four cases requiring a hearing and 70 others that do not).

The opportunity cost of an idle assignment depends on the value of the assignment, the value of the spectrum in its next best use, the delay needed to make the assignment, and the discount rate used. Robinson reports that the typical time required to resolve a set of mutually conflicting applications by a hearing is 3 years. The opportunity cost is therefore 3 years of the rental value of the license. Using a 10 percent interest rate as the social rate of discount, 3 years of lost use of the assignment amounts to about 25 percent of the value of the license.[17] Since many cases are settled short of a full hearing, this fraction over-states the loss. In the event of a settlement prior to a hearing, we will take the administrative delay to be one year, resulting in a loss of 9 percent in the license's value. The average loss is therefore 10 percent of the license's value $((0.09 \times 70 + 0.25 \times 4)/74)$. With these figures the costs of the present system of assignment for a license involving three competing applicants, each paying $25,000 for representation, include $75,000 of participation costs, about $7,500 of opportunity costs, and $5,400 of administrative costs, or about $87,900 overall. As can be seen, the administrative costs (as Robinson suspected), are relatively unimportant. The private costs of participation dominate, and the overall costs about equal the assignment's value.

However, the social costs will be lower than this because of the fact that most of the private costs are a transfer. The same is true of the FCC's administrative costs, since the people processing MDS applications presumably could be employed in some other work. For instance, if we assume that the social losses associated with the private and administrative costs are only 20% of the total, then the social costs are about $24,000 per license (i.e., ($75,000 + $5,400)/5 + $7,500).

One issue not so far discussed is that the hearing does not guarantee a Pareto efficient outcome. Of course, if the successful applicant is allowed to resell the license costlessly and immediately, the availability of this market ensures a Pareto efficient outcome. However, the anti-trafficking rules forbid resale for one year, and the resale market is unlikely to operate without transactions costs. The calculations in the next section, however, take all these costs to be zero for the hearing. This is a conservative assumption, and biases our comparison in favor of the hearing.

5.3 Implications of Auctions and Lotteries[18]

As with the hearing, the costs of an assignment policy depend on several factors:

- The number of competing applicants and the implied value of the assignment,

- The cost of participating in the selection process,

- The administrative costs of the selection process, and

- The time required to complete the selection process.

Instead of presenting results for one or a few "typical" values of these parameters, a simple Monte Carlo model was used to generate at random 1,000 alternative combinations of these factors. The costs of the three alternatives (hearing, lottery, and auction) were then calculated.

This approach allows an exploration of the parameter space, testing the sensitivity of any conclusions to different combinations of parameter values. Therefore, parameter values were selected independently, and except in one instance the probability densities used were uniform.

(The empirical distribution in Table 2 was used to generate the number of applicants.) These distributional assumptions help to maximize the chances that the simulated cases include a wide range of possibilities, and consequently reveal whether one alternative is generally superior to the others. Table 4 gives the parameter values used. The first seven items in Table 4 were discussed in the preceding subsection. The following paragraphs briefly discuss the reasons why the other values were chosen.

We have assumed that 3 to 9 months are required to conduct either an auction or lottery. This time estimate is longer than the three months said by one source (CATJ) to be the time required to process uncontested applications. But, additional time will undoubtedly be needed to allow applicants to prepare for the auction or lottery.

In both the lottery and the hearing, the costs of participation determine the number who participate. In the lottery, as in the comparative hearing, rational individuals will be attracted by the chance of winning a valuable prize. If an unlimited number of risk neutral individuals can qualify to operate a station, additional applications will be received until the expected excess profits are reduced to zero. For instance, if a license is worth $75,000 and it costs $1,000 to apply, there would be 75 applicants. Lotteries of Federal oil leases are reported to have attracted thousands of individuals, each paying a nominal fee for a small chance at a large prize (Wall Street Journal, 1980). Because assuming free entry by risk neutral participants is consistent with the model of Section 4, it is our base case. However, risk aversion or some limit on the number of qualified applicants might reduce the

Table 4

RANGES OF PARAMETERS USED IN SIMULATION

	Lower Limit	Upper Limit
Number of applicants*	1	8
Representation cost per applicant	$ 15,000	$ 35,000
Cost per year of FCC staff time	$ 40,000	$ 80,000
FCC staff time required for hearing	1 month	3 months
Fraction of cases requiring a hearing	0	8/74
Time delay if NO hearing	4 months	21 months
Time delay if hearing	1 year	5 years
Time delay for auction or lottery	3 months	9 months
Participation cost in a lottery	$ 500	$ 1,500
Participation cost in an auction	$ 2,500	$ 7,500
FCC staff time required for either lottery or auction	2 weeks	2 months
Ratio of social to private costs	0.05	0.50

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* Number of applicants is distributed according to the empirical
distribution in Table 2.

number who participate. Therefore, we also simulated a case where it was
assumed that no more than 20 individuals would be found eligible. Based
on discussions with FCC personnel, we took the participation cost to be
between $500 and $1,500. (This may be high. One can enter an oil lease
lottery for about $25).

Now consider the auction. The table shows the cost of participation
to be $5,000, representing the costs of preparing the application, and of
planning and bid preparation. As in the other two assignment methods,
potential bidders must weigh this cost against their expected profits.
But, it can be shown that the potential profits of a bidder at an auction
decline at a rate proportional to $1/n^2$ instead of $1/n$, where n
is the number of participants in the auction.[19] Consequently, if the
license is worth $75,000 and the costs of participation are about $5,000,
the number of bidders will be about $\sqrt{15} = 4$. (This calculation assumes
that the bidders are risk neutral. As in the lottery, bidders' risk aver-
sion might lead to a smaller number of applicants.)

If auctions or lotteries are used, our econometric work in Section 4
suggests that the number of licenses available in a market will affect the
license's value, and hence the amounts bid in an auction and the behavior
of lottery participants. Therefore, in this subsection we will assume
that the spectrum allocation is not increased. This provides a clear
contrast to the alternative of increasing the spectrum allocation pre-
sented in the following subsection.

Table 5 shows the results of 1000 simulated cases. The table shows
that the auction is significantly less costly than the other two alterna-
tives. In terms of social costs, it is between one-third and one-fourth

Table 5

COMPARISON OF ASSIGNMENT COSTS[1]

	Comparative Hearing	Lottery	Auction
Costs of Administration	$ 5,320	$ 2,870	$ 2,870
	(58)	(30)	(30)
Costs to Applicants	77,300	77,300	16,000
	(1520)	(1520)	(197)
Opportunity Cost of idle assignment[2]	7,910	3,700	3,700
	(195)	(81)	(81)
Total Costs[3]	$ 90,500	$ 83,900	$ 22,500
	(1611)	(1588)	(270)
Social Costs[3],[4]	30,800	25,900	8,940
	(696)	(614)	(151)

NOTES: 1. Means of 1000 simulated cases. Standard errors of means are reported in parentheses. Values are rounded to not more than three significant figures.
2. Discounted at 10%.
3. Detail may not add to total due to rounding.
4. Equals opportunity costs plus a portion of all other costs. See text.

as expensive as the hearing. In fact, the auction was the lowest cost
alternative in all 1000 cases simulated. (Notice that, because the oppor-
tunity costs of the auction are less than for the hearing, the qualitative
conclusion that the auction is superior is not sensitive to the ratio of
social to private costs.)

Because the values reported are averages of independent and identi-
cally distributed cases, the central limit theorem implies that the means
of the simulation are normally distributed with the mean and standard
deviations shown. Moreover, the partial sums of the costs will be approx-
imately normal also. We can therefore test the hypothesis that, under the
assumptions of Table 4, the average social cost of one alternative is less
than the average social cost of another using a paired-t test. This was
done, using partial sums of 25 cases. The auction is significantly less
costly than both the hearing ($t = 6.35$, $df = 39$) and the lottery
($t = 5.64$) using this test. The lottery also is significantly less
costly than the hearing, however ($t = 5.79$).

The auction is superior because the costs to applicants are much
lower than for the lottery or the hearing. This is because comparatively
few individuals find it worthwhile to bid in an auction, whereas in both
the hearing and the lottery individuals enter the competition until the
sum of their participation costs equal the license's value.

Therefore, it may appear that if the total participation costs in the
lottery can be limited, it may be superior to the auction. For instance,
suppose that the FCC, by "pre-qualifying" lottery participants, limits the
number who can participate. Re-running the simulation with the additional
restriction that the number of participants in the lottery can never

exceed 20 makes the lottery the lowest cost option in 326 out of the 1000
cases.

However, like the hearing, the lottery does not automatically main-
tain the guarantee, provided by the auction, that the outcome will be
Pareto efficient. To ensure this, it is necessary to allow a resale
market—i.e., in a privately organized auction. Under the anti-
trafficking rules this is not allowed for one year. Moreover, unless the
transactions costs, and the costs of any additional delay in using the
assignment, are negligible, the cost of the lottery plus its after-market
may exceed the costs of the auction.

For example, suppose we take the transactions costs of the resale
market to be zero, and consider only the opportunity costs due to delay.
For a lottery with N participants, the probability that a resale will
occur is at least $(N - 1)/N$, i.e., almost one. In the worst case, when
the assignment is entirely idle for the additional year, the additional
opportunity cost is one more year's rent on the assignment. Re-running
the simulation with this extra cost and the restriction $N \leq 20$, we find
that the auction is once again the least costly alternative in all 1000
cases. For an intermediate case, assuming only half as large an oppor-
tunity cost on average, the lottery is superior in only 6 out of the 1000
cases. These results suggest that the lottery is unlikely to be less
costly than the auction, even with restricted participation, if the addi-
tional costs and delays of the resale market are allowed for.

5.4 Implications of an Increased Spectrum Allocation

The third alternative policy is to increase the spectrum available to MDS. This policy could also eliminate the delays and costs associated with hearings by making enough assignments available to accommodate all applicants without hearings. The proposed expansion of the allocation for MDS, coupled with sharing between MDS, ITFS, and operational fixed services, is an example of this policy.

The regression model estimated in Section 4 can be used to assess this alternative in several ways. First, one can look at the number of assignments that would have to be made available to eliminate multiple hearings. To do this, set the left hand side of the regression equation equal to 1 (i.e., set the expected number of applicants to 1), and solve for the number of assignments N. (Also, the two dummy variables are set to 1, which is consistent with $n = 1$ and $N > 1$). Using the method of Tin (1965), because the coefficient on N is a random variable, gives an approximate estimate of the mean required N and its standard error, namely 6.67 ± 3.83. For comparison, the sample mean number of applicants in 1975 was 3. Thus, in 1975 something like 7 ± 4 assignments would have been necessary in an average market to satisfy demand without resorting to hearings.

Repeating this calculation for 44 individual cities shows that the mean is misleading.[20] The largest five cities would require an average of 13.8 assignments. The largest (New York), is estimated to have a demand (at zero price) of 16.8 ± 9.1.

The disproportionate demand in the larger cities is even more apparent if we estimate the probability that there will be two or more

applications for a license when N assignments are available. This
calculation requires an assumption about the distribution of the error
term. In view of the many other approximations made up to now there is no
clear choice. Here, we assume the errors are normal, and calculate the
probability in each market using two different assumptions about the
number of assignments that would be allocated to MDS. First, we assume
that each market had a total of twelve assignments available (ten of them
newly allocated, plus the two originally available). Second, a tabulation
of "unencumbered" channels in FCC Docket 80-112 was used to give the total
number of available channels in each market.

From these calculations, it turns out that there are only four cities
in which the probability that more than twelve assignments are needed
exceeds 0.20 (New York, Los Angeles, Chicago, and Philadelphia). However,
in 14 out of the 44 cities, there are already fewer than 12 channels
available; not coincidentally, these tend to be the largest cities where
the demand for MDS assignments, and for spectrum for use by other radio
services, already is high.

When the availability of unencumbered assignments is considered,
there is a probability of 0.80 or more that there will still be conflicts
in the seven largest cities, while the probability of a conflict is under
0.10 in 28 others.

These results tell us something about the likely effect of the
changes proposed in Docket 80-112. On the one hand, in all but the
largest markets the proposed allocation of additional spectrum will
probably eliminate the need for comparative hearings because the demand
for assignments will be less than the supply. On the other hand, hearings

will still be needed in the largest markets, for the most valuable
assignments.

More generally, the results for MDS illustrate a point about so-
called 'spectrum scarcity." This phrase is usually used to describe a
situation where there the demand for spectrum (at a zero price) exceeds
the supply. However, there is likely to be substantial variation in the
value attached to the spectrum. Hence, a system that allocates spectrum
uniformly nationwide almost inevitably causes spectrum to be idle or
underused in some areas, while keeping it "scarce" in other places.

The costs of this method of avoiding comparative hearings are diffi-
cult to assess. If we ignore the opportunity costs associated with allow-
ing MDS rather than some other service to use spectrum, the apparent costs
of continued hearings fall dramatically because hearings have been   elim-
inated in most markets. However, there _are_ alternatives to MDS, and deny-
ing them spectrum does have costs. For example, the "unencumbered"
channels would also be available for instructional television (ITFS) and
private microwave systems. But, there is no information on their value
(their licenses were not even awarded in comparative hearings), so it is
not possible to make a cost estimate for this alternative.

6.   CONCLUSION

The present system of assigning licenses using an administrative

process is, as shown above, costly and economically inefficient. In the

comparatively small MDS service, the costs of assignment appear to be a

substantial fraction of the value of the license. The costs of assignment

associated with more important services (e.g., television broadcasting or

domestic satellite) sharing the economic characteristics of MDS may bear a

comparable relationship to the much larger value of the licenses.

The traditional response to situations where the demand for spectrum

exceeds its supply has been to allocate more spectrum. This policy's

costs cannot be estimated without a knowledge of the value lost when other

services are displaced. However, our analysis suggests that a uniform

increase in an allocation may have to be very large if those areas of the

country with the most intense demands are to be satisfied. Such increases

are likely to leave much of the increased allocation idle or underused

elsewhere.

In contrast, auctions appear to have lower social costs than compara-

tive hearings. Not only are delay and administrative costs less, but the

auction mechanism prevents wasteful competition among the applicants for

the rents associated with the assignment. Lotteries (with costless,

unlimited resale) also are less costly because of reduced delays and

administrative costs. However, the simple lottery mechanism does not

eliminate the losses from rent-seeking. Moreover, if a policy restricting

the number of lottery participants is used to reduce these losses, resale

of licenses won in the lottery must be allowed in order to gain the

auction's guarantee of an economically efficient allocation.   Such a

resale market involves additional transactions costs, administrative costs and delays. When these are included, the full cost of the lottery probably exceed the cost of an auction, even though the cost of the lottery portion alone may be less.

FOOTNOTES

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simulation reported in Section 5. The author is solely responsible

for any opinions or remaining errors.

1. FCC Common Carrier Docket 80-116, Notice of Inquiry and Notice of

   Proposed Rulemaking, issued March 19, 1980.

2. The rules governing MDS are contained in Part 21, Subpart K of the

   FCC's Rules and Regulations (47 CFR 21), hereafter cited as FCC

   Rules.

3. Report and Order, Docket 19493, 35 FCC 2nd 154 (1972) and 45 FCC 2nd

   616 (1974), reconsideration denied 57 FCC 2nd 301 (1975).

4. FCC Docket 80-116, p. 4.

5. Prior to Ashbacher, the FCC apparently set some conflicting applica-

   tions for a hearing, but issued a license without a hearing (presum-

   ably after a public interest finding) in other cases.

   326 U.S. 338, n. 1.

6. See Docket 80-116. For instance, technical factors often seem to be

   similar for each applicant. Indeed, one instance is reported in

   which the hearing process apparently induced applicants to make their

   applications more uniform (Docket 80-116, pp. 7-10). In several

early cases, the winning applicant was awarded preference for quality

and reliability of service because it proposed to offer a "hot

standby" transmitter. This decision apparently induced a flurry of

amendments to pending applications adding a hot standby transmitter.

7. Docket 80-116, p. 28.

8. The amendments are contained in Public Law 97-259, Section 115. The

    second notice of proposed rulemaking in General Docket 81-768

    contains the proposed lottery rules for the low power television and

    television translator service, the public mobile common carrier radio

    service (except cellular radio), and certain private radio services.

9. E.g., Butters (1975). See Engelbrecht-Wiggans (1980) for a survey of

    this and other auction mechanisms, and Agnew, et al (1979) Chapter

    VIII for a discussion of auctions as they are related to spectrum

    management.

10. This can be found by assuming that all other applicants $j \neq i$ have

    chosen $x_j^* = x^*$, and finding the optimal $x_i = x_i^*$. The value of

    x_i^* which also equals x^* is the desired Nash equilibrium.

11. The inclusion of such variables on the right hand side of a regres-

    sion equation explaining n^* introduces a simultaneity problem,

    because these variables reflect some of the applicant's decisions.

    Ideally, the solution to this simultaneity problem would be the

    specification of additional equations corresponding to a nonsymmetric

    equilibrium. This specification might suggest appropriate instrument

    variables. However, no such model exists nor does the data available

    suggest any obvious instrumental variables. Thus, the possibility of

    simultaneous equations bias must be kept in mind.

12. For examples of the techniques that could be used, see Hausman and

    Wise (1978) and Heckman (1977).

13. Although this criterion is standard in applied welfare economics, its use is not uncontroversial. Whether some more elaborate criterion should be used here, however, is beside the point in view of the limited data that we have on demand.

14. The rules are as they are because spectrum management is administered hierarchically. First, "services" are "allocated" a band of frequencies. Then, individuals are "assigned" to a particular frequency within the band for their service. This paper is concerned with the assignment issue, while the imposition of restrictions on service is an allocation issue. Relaxing these restrictions within the MDS service raises thorny spectrum management issues going beyond MDS. As noted above, one of the proposed FCC actions would allow sharing of spectrum between MDS and ITFS and OFS. If we use private value as a measure of social value, we may understate the social value by at least the value of this change.

15. This value is strikingly less than the value of a commercial television broadcasting license. Estimates of the value of a "typical" VHF television station, for example, based on capitalization calculations, are around $2 million (Crandall, 1978). VHF stations owned and operated by one of the three major networks, all of which are in the top television markets, may be worth almost $60 million dollars each (Webbink, 1978). One possible reason for this disparity is that MDS channels cover a smaller market area than television stations.

16. This is, of course, the classic rent-seeking argument of Posner (1975) and Kreuger (1974).

17. This fraction is based on the amortized value of the license, and is given by $1 - (1 + r)^{-T}$ --where r is the discount rate and T is the length of the delay. For $r = 0.10$ and $T = 3$ this factor is 0.25.

18. There is growing literature about the theory of auctions (e.g., Englebrecht-Wiggans, 1980). Unfortunately, most of this theory is inappropriate for our problem. There are two reasons for this. First, the essential feature of the auction models is that bidders' estimates of the value of an object differ from each other. However, the available data only reveals variations in the value of different licenses, and the distribution of one tells us nothing about the distribution of the other (see Agnew, et al., 1979, pp. VIII-35 ff.). Second, although auction models of increasing generality are available (e.g., Milgrom and Weber, 1980), these models are still not general enough to describe real auctions for resources such as radio licenses. For example, license auctions involve the sale of multiple objects whose values may not be independent (because of network interactions), and these sales occur at different times. A more complete anlysis of this area must await more complete models as well as data on individual variations in value estimates.

19. See Wilson (1977).

20. The calculation was done for 44 of the top 50 cities listed in FCC Docket 80-112. That list includes six ADI's that are not included in the 1975 data on which the regression equation is based.

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AN ILLUSTRATIVE ANALYSIS OF TECHNOLOGICAL ALTERNATIVES FOR SATELLITE CONSTELLATIONS

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October 1979

Abstract

There are several indications that the demand for satellite communications services in the domestic market will soon exceed the capacity of the satellites currently in place. Two approaches to increasing system capacity are the expansion of service into frequencies presently allocated but not used for satellite communications, and the development of technologies that provide a greater level of service within the currently-used frequency bands. This paper is directed towards the development of economic models and analytic techniques for evaluating these capacity expansion alternatives.

The first part of the paper provides a brief overview of the satellite orbit-spectrum problem, and also outlines some suitable analytic approaches. This is followed by an illustrative analysis of domestic communications satellite technology options for providing increased levels of service. The analysis illustrates the use of probabilities and decision trees in analyzing alternatives, and provides insight into the important aspects of the orbit-spectrum problem that would warrant inclusion in a larger-scale analysis. Finally, the application of such analytic methodologies to the examination of satellite R&D decisions such as those faced by NASA is discussed.

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FOR SATELLITE COMMUNICATIONS

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PROGRAM IN INFORMATION POLICY

Engineering-Economic Systems Department
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ABSTRACT

There are several indications that the demand for satellite communications services in the domestic market will soon exceed the capacity of the satellites currently in place. Two approaches to increasing system capacity are the expansion of service into frequencies presently allocated but not used for satellite communications, and the development of technologies that provide a greater level of service within the currently-used frequency bands. This paper is directed towards the development of economic models and analytic techniques for evaluating capacity expansion alternatives such as these.

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Section I

OVERVIEW OF THE APPROACH

1. Introduction

This paper begins the development of economic models
and analytic techniques for evaluating NASA communications-
satellite R&D decisions. First, a brief overview of the
communications satellite orbit-spectrum problem is provided.
This overview describes the need for structural economic
models that characterize both the systems demand for
satellite communications services as well as the supply of
such services under a wide range of technology and policy
options. The overview also describes the need for methodol-
ogy to analyze NASA communications satellite R&D alternatives,
taking account of considerable market and technology
uncertainty.

The second part of the paper provides an illustrative
analysis of U.S. domestic communications satellite technol-
ogy options for providing increased levels of domestic com-
munications services within the constraints of orbit geom-
etry and present frequency spectrum allocation to domestic
communications satellites. The analysis illustrates the
use of probabilities and decision trees in analyzing tech-
nology alternatives and provides insight into the important

aspects of the orbit spectrum problem that must be dealt with in a full-scale analysis.

The final section of the report outlines how analyses of the type described in the preceding section can be used to examine satellite R&D decisions such as those faced by NASA.

2. Background

The allocation of geosychronous orbit positions and frequency spectrum to communications satellite use is a complex technical, economic and political problem. The U.S. domestic market will be considered in this discussion as an illustration of these problems.

There are presently three frequency bands allocated to U.S. satellite communications: 4/6 GHz (C band), 12/14 GHz (Ku band), and 20/30 GHz (Ka band). Interference considerations limit the use of the geosynchronous arc, and projections of demand growth indicate that the orbit-spectrum capacity in the C band and Ku band will be fully utilized within a few years. The Ka band is not yet utilized for satellite communications and presents some technical and cost disadvantages relative to the C and Ku bands. One option for expanding domestic satellite communication services is to pursue development of Ka band capability.

In addition to increasing the amount of orbit-spectrum allocated to communications satellites, there are many

technical alternatives for providing greater services within
a fixed orbit-spectrum. These technical alternatives include
changes in satellite and earth station design involving signal
processing, antenna design including polarization, demand
assignment among a pool of satellites, use of spot and inter-
satellite beams and changes in interference design parameters.
These technical alternatives offer the possibility of a
several-fold increase in communications services for a fixed
amount of orbit-spectrum resource.

The demand for domestic communications satellite services
has expanded rapidly. In some cases communications satellites
have diverted voice and data communications from possible new,
more costly terrestrial communications capacity. In other
cases, the increasing economic advantage of communications
satellites has reduced the costs of long-distance communica-
tions, particularly video, and has resulted in the development
of new communications services that would otherwise have been
uneconomic.

It is very difficult at this time to foresee what
balance or imbalance will result between the technical alter-
natives for expanding orbit-spectrum capacity and the demands
for communications services. Moreover, the demand depends on
the costs of satellite communications services in relation to
the costs of terrestrial communications and the benefits of
additional communications. In addition the balance is sensi-
tive to current R&D decisions to develop technology as well as

policy decisions to change the allocation or price of the orbit-spectrum.

3. NASA's Role

NASA's role in developing new satellite communications technology is articulated in recent testimony of Associate Administrator Anthony L. Calio before the House Subcommittee on Space Science and Applications.[1] NASA plans to meet the need for improved effectiveness and efficiency in the use of the limited resources of the radio spectrum and geosynchronous orbit positions by:

    1) new technologies to expend the capacities of existing bands, and

    2) capabilities for functioning in the unused Ka band.

In the first category fall "frequency re-use" methods involving contourable-beam space antennas, onboard switching, signal modulation, and polarization techniques. NASA proposes to take a leadership role in developing these technologies for the Ka band:

> We propose to develope an understanding of Ka-band usage within a multibeam antenna research effort. We believe that a unified R&D effort built around these new technologies and techniques will best advance U.S. leadership in satellite communications and support industry's efforts to increase the capacity of the two lower-frequency commercial bands (C-band and Ku-band). Simultaneously, this activity will provide new information and confidence in equipment for Ka-band use for private commercial purposes. We have widespread, enthusiastic acceptance from the industry on these plans.
>
>   A. J. Calio, Testimony of
>   February 20, 1979, p. 23

In addition to its role in R&D, NASA provides technical advice to the FCC on spectrum allocation and equipment technical specifications. This role places NASA in a position to participate in a wide range of potential policy decisions on the mechanisms by which frequency usage will be regulated.

Finally, although NASA's role in the regulation of orbit-spectrum usage is limited to technical advice, it is necessary for NASA to take account of the effect o. future regulatory policy on the need for new capacity and technology. For example, government policy mandating or encouraging frequency re-use or conservation measures could have a major impact on the need for NASA's R&D on Ka band technology.

4. A Framework for Analysis

Decisions such as those associated with NASA's role in satellite communications are very difficult. While considerable information on the technology and market is available, not all of it is relevant or reliable. Many technology and policy alternatives are possible, but it is very difficult to comprehend the important interactions among the alternatives. And, even if one could project with certainty the outcomes of alternatives, there is still the problem of determining what we want or who is to pay the costs and share in the benefits.

At the beginning we must recognize that no forecasting or other analytic methodology can eliminate uncertainty, make

decisions or replace the need for difficult value judgments.
Rather, analysis and models are useful in the decision pro-
cess if they facilitate the decision process in structuring
available information and value judgments or preferences in
a way that provides insights into the choices among alter-
nat·ves.

The objective, therefore, is to work towards the devel-
opment of a process of analysis that is supportive of the
NASA decision processes and makes appropriate use of models
and analysis.

5. Decision Analysis

Many aspects of communication satellite orbit-spectrum
decisions can be captured using readily understood techniques
of decision analysis.[2] In particular, the supply and demand
for satellite communications services are highly uncertain,
as are the technical outcomes of R&D. Early resolution of
technical uncertainty through R&D can have an immediate bene-
ficial effect on the market by facilitating good decisions on
the design and development of new satellites and the use of the
orbit-spectrum resource. The techniques of decision analysis
provide a way to put a dollar value on the benefits of resolv-
ing uncertainty through R&D, thus allowing the costs of R&D
to be rationally compared with the benefits.

Decision analysis is more than an analytical technique
for characterizing uncertainty in a decision problem. It is
also a process of analysis for bringing policy and technology

decisions into a logical relation with the available information, alternatives and preferences.

Typically a decision analysis is carried out with the close involvement of many technical specialists and the responsible executive officials. Through an iterative process of information structuring and alternative generation, a sequence of analyses is performed. The end product is not the analysis but is the insight and communication that is achieved by the participants in the analyses. This process has been successfully demonstrated in many public and private decision settings involving R&D, public regulatory policy, corporate new product decisions, environmental planning and facility capacity expansion.

As a first step towards such an application of decision analysis to communications satellite R&D and policy decisions of interest to NASA, we have developed the illustrative example in Section II of this paper.

6. Structural Modeling

One of the aspects of the decision analysis approach that deserves special attention in the case of satellite communications planning is the complexity of the interactions among the competing satellite and terrestrial communications systems and the demands for communications services. For example, as the cost of communications is reduced by technological advances, new demands for communications services appear. These demands cause the capacity of existing systems to be fully utilized

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and create a need for new systems that compete for scarce
spectrum and orbital positions with existing systems.

Attempts to use simplified models of the communica-
tions market are generally not very satisfying. A typical
approach is to forecast the magnitude of future communica-
tions demand categorized by type of communication, video,
data, voice. But in a world where the distinctions between
different communication techniques are becoming fuzzy and where
the costs of communication, including travel and mail, are
changing rapidly, forecasts that extrapolate from past demand
data are not very accurate or useful.

A modeling approach that has been applied successfully
in many industries is a structural modeling approach. In
this approach, the demands for communications are characterized
in terms of basic end-use services such as person-to-person
and broadcast communications and in terms of the time urgency
and content of information to be communicated. Specific end
use market segments, such as residential, large business, and
small business might be distinguished.

The alternative communications modes, such as voice,
video, data, mail, and travel, available to each end-use would
be identified and the demands for each derived from the basic
end-use data and the prices charged for each service. These
prices would be computed with bases of information character-
ized in the supply side of the model.

Communications services can be provided by a large number of alternative technologies. Each of these technologies has its own unique resource requirements in terms of spectrum resources, capital resources, reliability, and types of communications that can be carried out. The prices of these services are generally determined in part by economic forces and in part by a regulatory policy that allocates scarce public resources and controls prices of some services. These prices and the regulatory policies determine which technologies are developed and utilized to meet demand. The prices charged for the communications services in turn influence demand as described earlier.

In a structural model of the communications market, each generic communications technology would be identified, and the direct capital operating and other costs associated with each unit deployed would be characterized as inputs to the model and would be adjusted within the model to account for inflation and technological learning effects. In addition, the technical information required to compute the amount of spectrum and orbit resources required for a given mix of communications services would be provided.

The model would utilize this and other information to simulate the expansion and operation of an entire communications system including all major forms of communications over a period of twenty or more years. The model calculations

would be carried out iteratively because of the simultaneous nature of the interaction between supply, demand and prices.

A structural model of this type would allow investigation of the penetration of different technologies under a variety of assumptions regarding the outcomes of R&D and public communications regulatory policy. Such a model would also be a useful tool for investigating alternative communications satellite regulatory policies.

In this paper we have not attempted any significant structural modeling of the communications market and have instead relied on existing forecasts as a basis for the illustrative decision analysis. This lack of emphasis on a structural model of the communications market should not, however, be taken as an indication of the lack of a need for such modeling. The illustrative example as developed in this paper makes clear the need for better models of the communications market as an aid to communications satellite R&D planning.

Section II

THE ILLUSTRATIVE ANALYSIS

1. Introduction

This section of the paper describes an illustrative
application of decision analysis to technology decisions
affecting domestic communications satellites. First we
examine the likelihood of satellite services demand exceed-
ing the system capacity in the future. Having shown the
uncertain need for additional capacity, two options for
increasing orbit-spectrum capacity are discussed and com-
pared: the development of conservation and re-use technol-
ogies for the frequency bands currently in use, and the
introduction of service at a higher frequency band (the Ka
or 20 to 30 gigahertz band).

Background information for the analysis is provided by
four contractor reports, supplied by NASA. The contractors
are Western Union and ITT, whose studies concentrate on the
demand for Ka band satellite services, and Hughes and Ford
Aerospace, who provided "systems studies" of the technical
and cost details of alternative Ka systems.

The first part of the analysis develops a simplified
demand model, based largely on the ITT analysis. ITT's
forecasts are presented and discussed. Then a probabilistic
version of the ITT forecast is developed, based on a set of
illustrative estimates by the authors. The next section of

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the paper examines system capacity. Again the deterministic data from the ITT analysis are used as a base on which to build a probabilistic forecast. The probabilistic forecasts for demand and capacity allow us to examine the question of system saturation in a decision analysis framework.

The next section of the paper considers system expansion through the use of a Ka band service or frequency re-use. A series of scenarios demonstrate how the technologies might be used to meet demand. The comparison of technological alternatives through the use of cost information is discussed and an illustrative cost comparison of Ka service to re-use is presented.

2. Demand

A forecast of the future demand for satellite services is essential to any evaluation of alternative satellite systems. Ideally, the demand model would build a forecast by aggregating over the various types of service. In keeping with a decision analysis approach, the explicit consideration of uncertainty would be desirable.

Below we develop a simple model of demand. We first develop a framework for a general satellite demand model. The model is derived largely from the ITT analysis. ITT's data and results are briefly discussed. In the latter part

of the section we develop a probabilistic forecast, using
a set of illustrative probability distributions.

The data developed in the Western Union report is in
a different form from that used by ITT, and is not used
in our demand model. The Western Union data is presented
and compared to the ITT data in Appendix A.

Outline of a General Satellite Demand Model. A frame-
work for a satellite demand model is shown in Figure 1. The
model estimates satellite traffic in equivalent transponders
for a given service (voice, data, or video) in a given year.

We would expect the demand model to be driven by price,
which in turn will depend to some degree on the cost of both
terrestrial and satellite technologies. The model then de-
termines the total annual demand for long-haul telecommunica-
tions traffic. However, of greater interest is the peak level
of telecommunications traffic. This will depend on total
traffic load, and also on peak hour pricing strategies. The
peak demand will determine the capacity equirements.

The next step is to determine the satellite share from
the total peak demand. We can think in terms of a "satellite
capture ratio," or market share, that determines the percent-
age of the total demand that goes to satellites. This ratio
will vary for different types of service. The major factor
in determining this ratio for a given type of service are
the relative costs of terrestrial and satellite technologies
for a transmission of a given distance. Finally, the average

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FOR A GIVEN YEAR
AND TYPE OF SERVICE
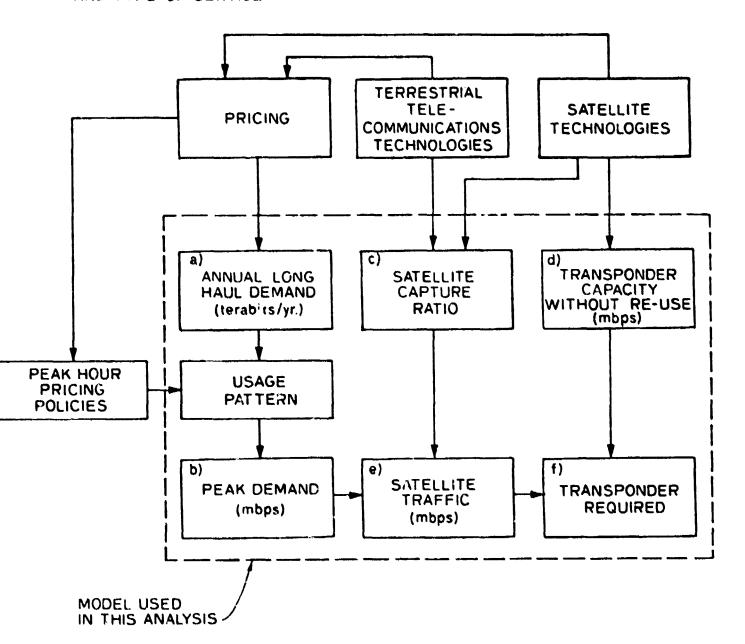
Fig. 1: Framework for Satellite Demand Model

capacity of transponders in use will determine the
demand for transponders.

A More Limited Demand Model. The ITT analysis does
not explicitly consider price as a factor in demand. Pre-
sumably the assumption is that demand is simply not price
sensitive, or that price can be determined directly from
satellite systems cost estimates and from projections of
terrestrial tariffs. This leads us to a simpler demand
model, which is shown within the dotted lines in Figure 1.
Price and cost characteristics of terrestrial and satellite
technologies are considered implicit to the resulting model.

Below we discuss the components of the modified model,
and present the relevant data from the ITT report.

a) Yearly Long-Haul Demand. ITT's forecast of yearly
   demand for the years 1980, 1990, and 2000 is shown
   in Table 1. It is broken down into three services
   types: voice, data, and video. Note a common unit,
   terabits per year, is used for each type of service.
   The share of the traffic attributed to each type of
   service is also shown for each year.

b) Peak Demand. Peak demand determines the overall
   capacity required. Peak demand will depend on the
   overall traffic level, patterns of usage, and peak
   period pricing policies.

   Table 2 shows ITT's forecast for peak demand, in
   millions of bits per second. The available

Table 1:   ITT - Forecast of Yearly Demand, in Terabits/yr.

	1980	1990	2000
Voice	559,000 (74%)	1,402,000 (76%)	2,891,000 (77%)
Data	112,000 (15%)	281,000 (15%)	437,000 (12%)
Video	82,500 (11%)	170,700 (9%)	417,300 (11%)
Total	753,500 (100%)	1,853,700 (100%)	3,745,300 (100)

Table 2:   ITT - Forecast of Peak Hour Demand (millions of bits per second)

	1980	1990	2000
Voice	43,800 (65%)	108,100 (63%)	204,700 (64%)
Data	20,667 (31%)	50,869 (30%)	78,853 (25%)
Video	2,891 (4%)	13,252 (7%)	37,980 (11%)
Total	67,358 (100%)	172,221 (100%)	321,533 (100%)

Table 3:   ITT - Ratio of Peak Hour to Average Demand (Derived)

	1980	1990	2000
Voice	2.5	2.4	2.2
Data	5.8	5.7	5.7
Video	1.1	2.4	2.9

information gives no indication of the methodology used to determine peak traffic. For information purposes, the ratio of peak demand to average demand for each of the services is shown in Table 3.

c) <u>Satellite Capture Ratio</u>. The satellite capture ratio refers to the percentage of long-haul traffic (defined by ITT as traffic transmitted more than 200 miles) that is handled by satellite. This will be different for different types of service.

ITT's capture ratios are presented in Table 4. The report does not state how the ratios were determined. One way of determining capture ratios is presented in the Western Union report. They consider the relative costs of satellite and terrestrial service to split the demand up. They develop a set of terrestrial/ satellite crossover curves that determine the relative costs for various distances of transmission. However, the approach may still be simplistic. The ratio can also be different between sets of city pairs the same distance apart, depending on factors including traffic density, geography, etc.

d) <u>Satellite Traffic</u>. Satellite traffic is an intermed- iate result. It is computed as the product of peak demand and the satellite capture ratio for each type of service.

Table 4:   ITT - Satellite Capture Ratio, in percent

	1980	1990	2000
Voice	2	15	25
Data	1	50	60
Video	50	60	60

Table 5:   ITT - Unit Transponder Capacity, in MBPS

Year	Capacity
1980	42
1990	72
2000	108

Table 6:   ITT - Demand for Transponders (in 36 MHz equivalent
                                          transponders)

	1980	1990	2000
Voice	21 (34%)	225 (33%)	474 (42%)
Data	5 (8%)	335 (51%)	436 (39%)
Video	35 (58%)	110 (16%)	211 (19%)
Total	61 (100%)	690 (100%)	1121 (100%)

e) <u>Unit Transponder Capacity without Re-use Technologies</u>.
ITT estimates that transponder capacity (in terms of
bits received per time period) will increase as time
goes on, as shown in Table 5. Because re-use technolo-
gies are not explicitly considered in the ITT analysis,
we have assumed the capacity increases stem from factors
other than the re-use technologies considered later in
this report. Thus the data given in Table 5 are taken
as base capacities, which can be increased by various
re-use technologies.

f) <u>Transponders Required</u>. The resulting number of trans-
ponders required can be calculated as the quotient of
satellite traffic and transponder capacity. ITT's
forecast is shown in Table 6.

<u>Probabilistic Analysis</u>. Below we use the simple model
outlined in Figure 1 and a set of illustrative probability
distributions on the model components to demonstrate the con-
struction of a probabilistic forecast. The output will be a
probability distribution on total transponder demand for a
given year.

The equation below determines the demand for a given type
of service in a given year:

$$DT_{ij} = \frac{PKD_{ij}}{TC_j} \cdot SCR_{ij} \qquad\qquad (1)$$

where: i = type of service: voice, data, or video

j = year

DT = number of transponders required

PKD = peak long-haul demand, in MBPS

TC = unit transponder capacity, in MBPS

SCR = satellite capture ratio

Below we will drop the subscript j . Just one year, 1990, will be considered.

The procedure to be used here will be to assign a probability distribution to each of the state variables. These can be transformed, through the use of equation (1) into a distribution on the number of transponders required for each type of service for 1990. This can further be converted into a distribution on the total number of transponders required.

Probability Distributions on Model Parameters. In general, a continuous or a discrete probability distribution can be assessed by one or more "experts" for each of the state variables. Techniques for the elicitation of distributions are well-established.[3] The distributions we have used here are purely illustrative. In each case a discrete distribution with three branches is used. The value from the ITT report is

used as the "nominal" case and is assigned a probability of
.5 . "Low" and "high" values, each with a probability of
.25 are also assigned. The values assigned are shown in
Table 7.

It can be expected that there is probabilistic depen-
dence between certain sets of variables. In the first part
of the analysis, where we produce distributions on demand
for each of the three types of service, we assume there is
no dependence between the peak demand PKD_i , the capture
radio SCR_i , and the transponder capacity TC . It would
in general be possible to include the dependencies by
assessing conditional distributions, or by restructuring
the model to include additional variables that explicitly
deal with the dependencies, allowing unconditional assess-
ments to be made.

Distribution on Transponders Required for Each Service
Type. A probability tree, such as the one shown in Figure 2
for voice, can be constructed for each service. From the
tree we ca. generate a probability distribution on the number
of transponders required. The distribution has 27 branches.
Because the distributions for voice, data and video traffic
are intermediate results in terms of this analysis, they
are not presented here; they are shown in Appendix B.

Distribution on Total Number of Transponders Required.
It is also possible to use the assigned distributions to
produce a distribution on total demand. This requires

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Table 7:   Probability Distributions for Demand Model for 1990

		Low (prob = .25)	Nominal (prob = .50)	High (prob = .25)
PKD	(Peak Demand)			
	– Voice (mbps)	86,480	108,100	140,530
	– Data (mbps)	25,434	50,869	76,303
	– Video (mbps)	6,626	13,252	33,130
SCR	(Capture Ratio)			
	– Voice	.10	.15	.25
	– Data	.4	.50	.65
	– Video	.45	.60	.7
TC	(Transponder Capacity) (mbps)	54	72	108

PKD $\begin{pmatrix} \text{peak} \\ \text{demand} \end{pmatrix}$	SCR $\begin{pmatrix} \text{satellite} \\ \text{capture} \\ \text{ratio} \end{pmatrix}$	TC $\begin{pmatrix} \text{transponder} \\ \text{capacity} \end{pmatrix}$	DT $\begin{pmatrix} \text{derived} \\ \text{demand in} \\ \text{transponders} \end{pmatrix}$
		54 pr = .25	160
	.10	72 pr = .5	120
	pr = .25	108 pr = .25	80
		54	240
86,480 pr = .25	.15 pr = .5	72	180
		108	120
		54	400
	.25 pr = .25	72	300
		108	200
		54	200
	.10	72	150
		108	100
		54	300
108,100 pr = .50	.15	72	225
		108	150
		54	500
	.25	72	375
		108	250
		54	260
	.10	72	195
		108	130
		54	390
140,530 pr = .25	.15	72	293
		108	195
		54	651
	.25	72	488
		108	325

Fig. 2: Probability Tree for Voice Demand

further consideration of the dependencies between the
types of service. Two possible approaches for the purposes
of the demonstration are: 1) to assume independence between
the peak demand for each service and between the capture
ratio for each service; or, 2) assume complete dependence
between the three peak demand variables, and complete depen-
dence between the three capture ratio variables. The latter
approach is used here. This means that if the voice peak
demand variable takes on its low value, the data peak demand
variable and the video peak demand variable also take on
their low values. The same applies to the capture ratio
variables. The assumption of complete dependence can be
partially justified as follows. There are several common
underlying factors that will influence peak demand for all
the types of service. These factors include new developments
in satellite technology, and general satellite service pricing
policies. With respect to capture ratios, the most important
underlying factor is the relative costs of satellite and ter-
restrial technologies; this should affect each of the three
service types in a similar way. The fact that these underly-
ing factors will influence the variables in a similar way for
each type of service indicates that some dependence between
demand for the three service types does exist.

The probability tree is shown in generic form in Figure
3, and the resulting cumulative distribution on total demand
is shown in Figure 4. The point estimates from the ITT and
WU reports are also shown.
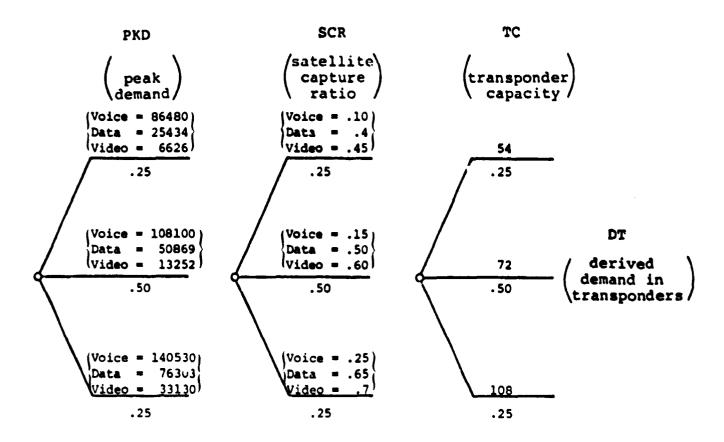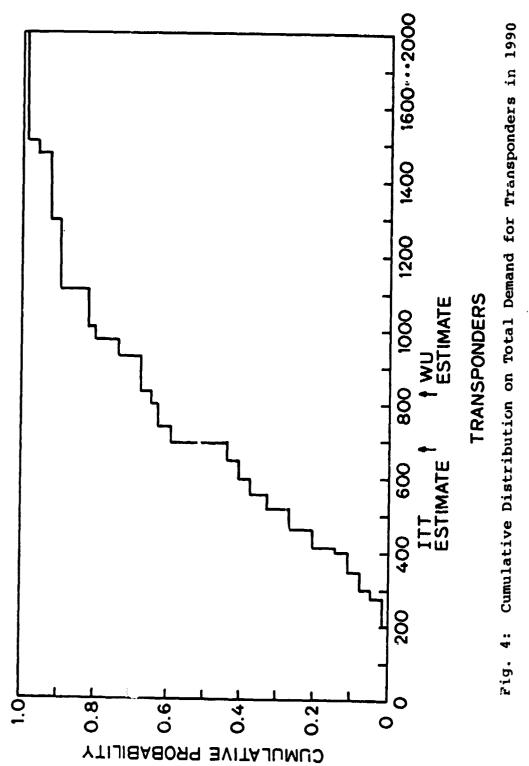
Fig. 3:   Probability Tree for Total Demand

Fig. 4: Cumulative Distribution on Total Demand for Transponders in 1990

3. System Capacity Without Re-Use

In this section we determine the capacity of the
domestic orbital arc, in terms of the number of domestic
satellites and the resulting number of transponders that
can be placed in orbit. The ability of each of the three
frequency bands to handle communications traffic is
limited by three factors:

- the intersatellite distance required to keep
  interference to acceptable limits--this determines
  the number of satellites that can be used;

- the number of transponders per satellite; and

- the fraction of the domestic orbital arc designated
  for use by the U.S.

The ITT report provides data on the first factor, and
presents an estimate of available capacity. We first sum-
marize that data. We then proceed in a manner analogous to
that used in the demand section. We present a simple model
that determines capacity from information on the three
limiting factors listed above. We use the ITT data as a base
from which to generate illustrative probability distributions
on each of the factors. From these distributions we derive
a probability distribution on capacity.

ITT Data

ITT presents three orbital spacing scenarios for the
C and Ku bands. They are shown in Table 8. Although it is not
explicitly stated, they appear to take 3° as the most likely
Ka band spacing.

Table 8:   ITT - Satellite Spacing Scenarios

Scenario	C band	Ku band
Minimum Capacity	4.5°	4.5°
Most Probable	4°	3°
Maximum Capacity	3°	3°

Table 9:   ITT - Resulting System Capacities (in Transponders)

Scenario	C band only	C and Ku bands combined
Minimum Capacity	216	432
Most Probable	264	648
Maximum Capacity	384	768

The ITT estimates of C and Ku band capacities (in transponders) are shown in Table 9. They present 3 estimates, corresponding to the three spacing scenarios. The method by which the estimates were derived is not currently available. In comparison with our estimates of capacity presented below, the results seem rather high.

Probabilistic Analysis. The following equations can be used to determine maximum capacity, in terms of transponders:

a) combined capacity of C and Ku band:

$$CAP_{ck} = \left(\frac{72}{S_c} \cdot t_c + \frac{72}{S_k} \cdot t_k \right) p$$

b) combined capacity of C , Ku , and Ka band:

$$CAP_{cka} = CAP_{ck} + \frac{72}{S_a} \cdot t_a \cdot p$$

where:

S_c = satellite spacing in C band, in degrees

S_k = satellite spacing in Ku band, in degrees

S_a = satellite spacing in Ka band, in degrees

t_c = average number of transponders per satellite, C band

t_k = average number of transponders per satellite, Ku band

t_a = average number of transponders per satellite, Ka band

72   = the size of the domestic orbital arc, in degrees

p   = fraction of the 72° designated for use by the U.S.

A probability distribution on capacity can be
produced by assigning probability distributions to the
variables in the above model. Again we have assigned
illustrative distributions, which are shown in Table 10.
The data on spacing is based on the scenarios in the ITT
report. It will be assumed there is complete probabilistic
dependence between S_c , S_k , and S_a . That is, if S_c
takes on its low value, S_k and S_a do also. The three
variables relating to satellite transponder capacity, t_c ,
t_k , and t_a , have been taken as certain for this analysis.

From these distributions, cumulative distributions on
capacity without and with the Ka band were derived; the
results are shown in Figures 5 and 6. Again, it is pointed
out these results assume no re-use technologies are applied.
The impact of re-use on capacity will be examined in
later sections.

4. The Probability of Saturation

In this section we determine the likelihood of system
saturation by 1990 if re-use technologies are not employed.
To do this, we compare our probability distribution on total
demand, from Figure 4, to the distributions on capacity with-
out and with the Ka band, shown in Figures 5 and 6 respec-
tively. We assume probabilistic independence between the
sets of variables making up the demand and the capacity
models.

Table 10:   Probability Distribution for the Capacity Model

Variable	low value (prob. = .25)	nomimal value (prob. = .5)	high value (prob. = .25)
s_c	4.5°	4°	3°
s_k	4.5°	3°	3°
s_a	4.5°	3°	2°
t_c	-	24	-
t_k	-	12	-
t_a	-	24	-
p	.33	.50	.75

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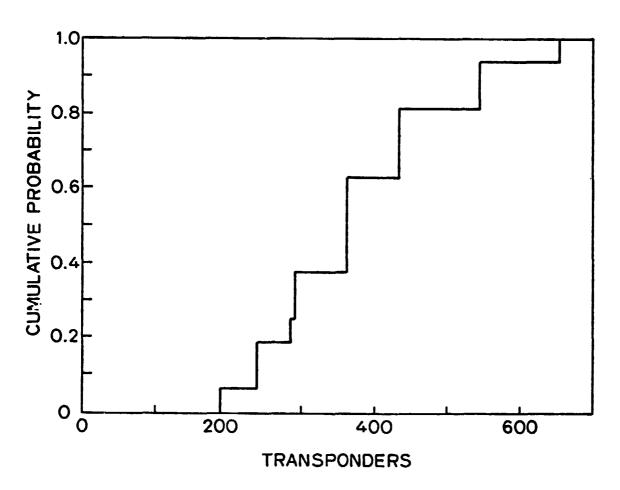
Fig. 5:   Distribution on System Capacity without Re-Use and without Ka band
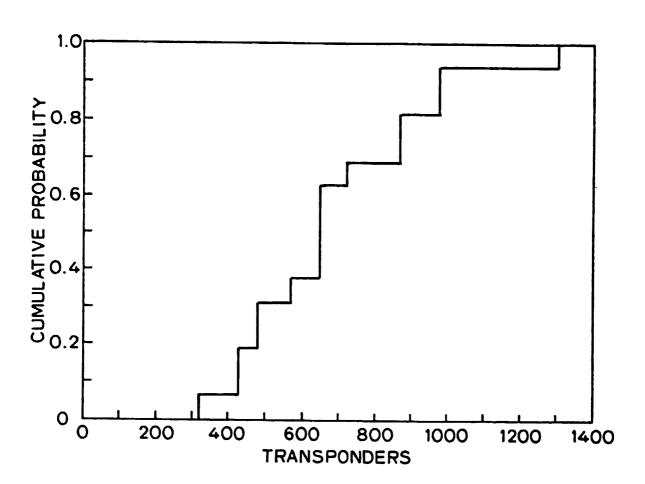
Fig. 6: Distribution on System Capacity without Re-use but with Ka band

We first examine the "most likely" values of the distributions. The median value of demand is 690 transponders; the median capacity without Ka is 360 transponders, and with Ka is 648 transponders. Using the most likely demand and capacity values, we can calculate that without Ka the system can meet only 52% of demand in 1990, while with the Ka band the system can meet 94% of the demand.

Moving away from the "most likely" case, we can use the complete distributions to calculate the overall probability of saturation; i.e., the probability that demand exceeds capacity. The equation used is:

Probability of Saturation =

$$\sum_{q \in Q} \text{Prob}\left(DT > q \mid CAP = q\right) \cdot \text{Prob}\left(CAP = q\right)$$

where Q is the set of all values in the capacity distribution, and DT is the demand for transponders. We have assumed probabilistic independence between demand and capacity.

Therefore:

Probably of Saturation =

$$\sum_{q \in Q} \text{Prob}\left(DT > q\right) \cdot \text{Prob}\left(CAP = q\right)$$

The result of these calculations are:

— without Ka band: .86 probability of saturation

— with Ka band: .54 probability of saturation

Thus without the Ka band and without re-use it is very likely that saturation will occur. Even with the Ka band, the probability of saturation is still greater than .5. This suggests re-use technologies will probably be needed if demand is to be met. In the next section we examine alternative ways of expanding system capacity.

5. Capacity Expansion Alternatives

If demand in 1990 exceeds the capacity of the C and Ku bands (as it appears likely it will), capacity expansion will be required. In this section we discuss how re-use and/or Ka band service might be used to provide additional capacity.

We will avoid consideration of the details of the technological alternatives employed. For example, there are many possible re-use technologies that are or will be available; some of these are coding and modulation techniques, dual polarization, antenna sidelobe suppression, satellite-to-satellite links, and the multiple beam antenna with on-board switching. In the remainder of the paper we assume that one aggregate re-use technology is available. The aggregate technology could include one or more of the above technologies. Presumably the technologies with the lowest marginal costs of use would be selected for use first. The exact configurations of a system would be determined by systems engineering studies. For Ka band service, we ignore attenuation and reliability problems, and assume the service provided is indistinguishable from C and Ku band service.

Analysis of Some Expansion Scenarios. The degree to
which expansion will be required depends on the demand level
in 1990. From the probability distribution on demand from
figure 5 we select three demand scenarios:

- "low"   : demand is 415 transponders

- "nominal":   "   690   "

- "high"   :   "   1100   "

In order to keep the analysis simple, we will not use
the probability distributions on capacity from Figures 5
and 6. Instead we will take capacity to be certain, and
assign the "most likely" values:

C band: capacity is 216 transponders

Ku band: "   144   "

Ka band: "   288   "

Finally, we will consider three technological alterna-
tives, and compare them in terms of their ability to meet
demand. They are:

A. Neither Ka band or re-use are available.
B. Ka band is available; re-use is not.
C. Ka band is not available; both the C and Ku
    bands can be re-used several (3 to 20)
    times, using an aggregate "package" of technologies.

The alternatives presented are just examples; the list is in
no way comprehensive.

The alternatives and the demand scenarios are laid out in
tree form in Figure 7. On the right side of the tree the
ability of the alternatives to meet each of the three demand
levels is described.

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| Alternative | Demand Level | Outcome |

low — Saturation - 87% of demand met

A
(no Ka
or
re-use)

nominal — Saturation - 52% of demand met

high — Saturation - great undercapacity -
only 33% of demand met

low — Capacity exceeds demand -
only 19% of Ka band needed

B
(Ka, no
re-use)

nominal — Capacity slightly short of demand -
94% of demand met

high — Saturation - only 59% of demand met

low — Only 15% of C and Ku bands need to
be re-used

C
(re-use,
no Ka)

nominal — Re-use 92% of C and Ku bands - need to
approximately double capacity

high — A large level of re-use is necessary -
about 3 times the C and Ku
capacity without re-use is
required.

Fig. 7: Scenarios

In Section 4, comparing the full distribution on total
demand to the distribution on total capacity led to the conclu-
sion that there is a probability of .86 that demand will exceed
capacity if neither re-use or Ka band are available. In the
cruder analysis here, we see that in no case can demand be met
by just the C and Ku bands without re-use. At the "low"
demand level, either a small amount of re-use or a small
portion of the Ka band are required to meet demand.

At the nominal demand level, the Ka band on its own
falls just short of meeting demand. Under Alternative C,
it is necessary to re-use the C and Ku bands so that capacity
is approximately doubled. It appears that given a moderate
level of success in developing either technology, this level
of demand can be met. If a large number of re-use technolo-
gies were to become available between now and 1990, there is
the potential for a large amount of overcapacity.

At the high demand level, the addition of the Ka band
alone does not come close to meeting demand. Under Alterna-
tive C, the C and Ku bands must each be expanded to triple
their base capacity in order to meet demand. Therefore
unless Ka band and/or re-use are successfully developed by
1990, a large gap between demand and supply could result if
the demand level is high.

Combining Ka Band and Re-use Technologies. In general,
there are many combinations of C band re-use, Ku band re-use,
and Ka service that can be used to meet demand. Examples of
combinations that could be used to meet the nominal demand
level of 690 transponders are shown in Figure 8. The graph
on the left of Figure 8 shows possible combinations if the
Ka band is not available; the graph on the right assumes Ka
band is available (but cannot be re-used). A vertical line
drawn at any point on a graph shows how demand is met: the
amount that C band is expanded over its capacity without re-
use, the amount that Ku band is expanded over its capacity,
and whether or not the Ka band is used.

If the demand for satellite services is taken as insen-
sitive to price, then the optimal choice of satellite tech-
nologies corresponds to the problem of finding the system
configuration that meets demand at least cost. In the next
section we introduce cost data into the analysis.

6. Analysis of the Comparative Costs of Alternatives

By quantifying the uncertainties relating to cost, we
can expand the decision analysis framework of the earlier
sections of the paper. Unfortunately, the cost data avail-
able so far, from the contractor reports and from other
sources, is sketchy. Below we present a general outline of
how the analysis should proceed. We then present an example
of a cost comparison between competing technologies, using
illustrative cost data.

a) without Ka band   b) with Ka band
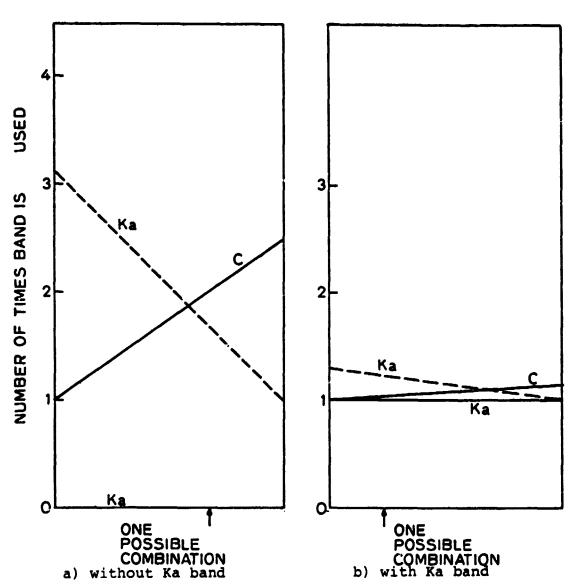
Fig. 8:   Possible Combinations of C band Re-use, Ku band Re-use,
          and Ka band to Meet a Demand of 690 Transponders

The General Framework. Figure 9 shows a decision tree,
in generic form, that determines the expected cost of meeting
demand for a given technological alternative. For example,
an alternative might be the use of the Ka band, or the intro-
duction of some combination of re-use technologies. There
are four state variables represented in the tree. The first
two variables are total demand, and system capacity without
re-use for each band. Comparison of the values taken on by
these variables determines to what extent frequency expansion
is needed. The last two variables are the technical perfor-
mance of the alternative at the level of service required to
meet demand (e.g., amount of re-use attainable), and the
resulting cost. In some cases the value of one or both of
these variables may be relatively certain. The last two
variables provide a general representation; they would appear
in different forms for specific analyses. The values at the
right side of the tree determine the cost of meeting the
resulting demand level. In some cases it may not be possible
to meet some high levels of demand with the given technologi-
cal alternative. "Rolling back" the tree determines the
expected cost of using the alternatives.

The cost of terrestrial technologies in direct competi-
tion with satellites will also determine the desirability of
using the various satellite technologies. The effect of com-
petition from terrestrial service will show up in the satel-
lite capture ratio in the demand model. Since we have even
less data on projected terrestrial costs than on satellite
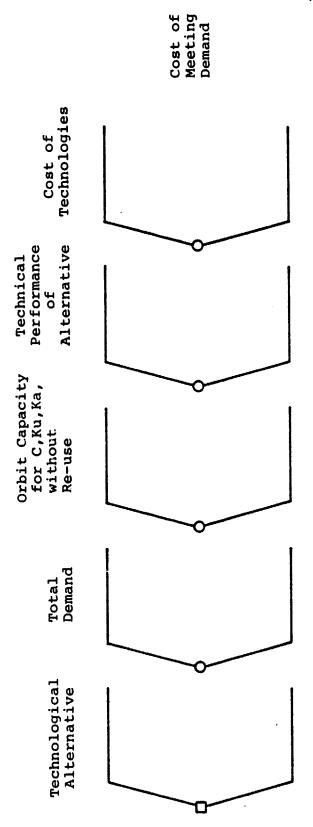
Fig. 9: Tree for Evaluating Competing Technologies

costs, we will assume the contractors' estimates of satellite

capture ratios included the possibility of new or improved

terrestrial technologies. As noted in Section I, it would be

desirable in the future to formulate a structural model that

approached the question of terrestrial/satellite tradeoffs

in a more comprehensive manner. Pricing policies should

certainly be included, as should latent demand--demand not

currently observable, but which might appear if the costs

were reduced substantially.

An Illustrative Cost Comparison of Ka Service to C Band

Re-use in 1990. The following analysis uses illustrative

cost data. Its purpose is to show how uncertainty about cost

enters into the analysis. A full description of an expanded

form of the example appears in Appendix C.

We compare two technological alternatives. The alterna-

tives are simply examples; many other possibilities exist.

The alternatives are:

1. C-band re-use. The C band spectrum is re-used

    through a variety of technologies. The Ku band is

    used before re-use is employed on the C band. The

    Ka band cannot be used. For the sake of compu-

    tational ease, we assume no re-use technologies are

    used for the Ku band.[4]

2. Ka band. The Ka band can be used. No re-use is

    possible for the C band or the Ku band. In perform-

    ing the analysis it was found that the capacity

available from the use of all three bands often

fell short of meeting demand.   Therefore re-use

of the Ka band only is allowed, say through the

use of spot beams with on-board switching.[5]

The decision tree for the analysis is shown in Figure

10.   There are four state variables: total demand, system

capacity, cost of C-band re-use, and Ka system cost.

The total demand distribution from Figure 4 was approxi-

mated by a three-branch distribution.   In order to reduce the

amount of analytic effort required, we again use determinis-

tic values for system capacity.   The values used are:

C   band: CAP_c =   216

Ku   band: CAP_k =   144

Ka   band: CAP_a =   288

Uncertainty on system capacity could be added to the analysis

with no change in the methodology used.

The basic unit of cost used is dollars per transponder.

We are interested only in relative costs.   It is assumed the

costs for the C and Ku bands are certain, while Ka band cost

is uncertain.   The following data are used:

Q_c =   cost/transponder in C-band   = $1

Q_k =   cost/transponder in Ku-band = $1.50

Q_a =   cost/transponder in Ka-band is described
            by the distribution:

$$\text{Prob}\left(Q_a = \$1.50\right) = .5$$

$$\text{Prob}\left(Q_a = \$5.00\right) = .5$$

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Technological Alternative

Demand

System Capacity

Cost of C-band Re-use

Ka System Cost
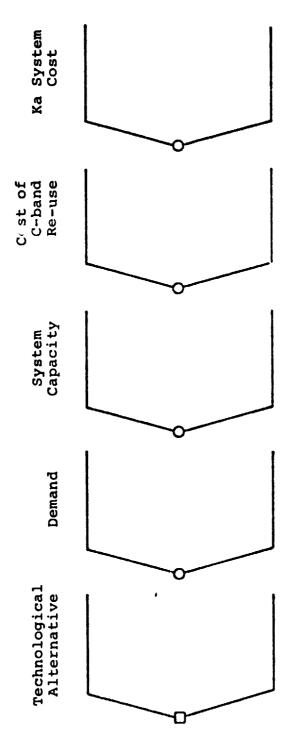
Fig. 10: Tree for C band Re-use vs. Ka band Comparison

A simple model of re-use cost is employed for C band re-use (and for Ka band re-use when required). It is assumed re-use technologies are added one at a time until demand is met. Each technology allows the entire spectrum capacity to be re-used; i.e., it doubles capacity. Cost increases for each re-use, as follows:

$$CRU(n) = Qm^n \qquad (2)$$

where:

CRU(n) = marginal cost per equivalent transponder when the spectrum is being used for the nth time

Q = cost per transponder without re-use

m = a multiplier (m > 1)

n = number of times the spectrum is being re-used

This model is used for illustrative purposes. Its form does seem plausible. The acquisition of data on re-use costs would allow this and alternative model forms to be tested with data and compared in terms of suitability.

For Alternative 1, C-band re-use, the multiplier is m_c, and is uncertain:

$$Prob\left(m_c = 1.2 \right) = .5$$
$$Prob\left(m_c = 2 \right) = .5$$

For cases where re-use is required for the Ka band, the multiplier m_a is taken to have the value of 1.2.

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Figure 11 shows the full decision tree, with the deterministic capacity variable removed. At the right side of each final node in the tree is the resulting minimum cost for meeting demand. The cost calculations are described in Appendix C.

The tree can be rolled back to yield an expected cost of meeting demand for each alternative. The results are:

Alternative 1, (C-band re-use):
        Expected cost = $1621

Alternative 2, (Ka band):
        Expected cost = $1802

Because the data used here is illustrative, no definitive statements can be made from the results. However, we can see how the data could be used for decision-making purposes. If Research Programs 1 and 2 were available that led respectively to Alternatives 1 and 2 being available in 1990, then it appears that Program 1 leads to a savings of $181 compared to Program 2. The steps involved in extending the analysis to give explicit consideration to R&D alternatives are discussed in the next section.
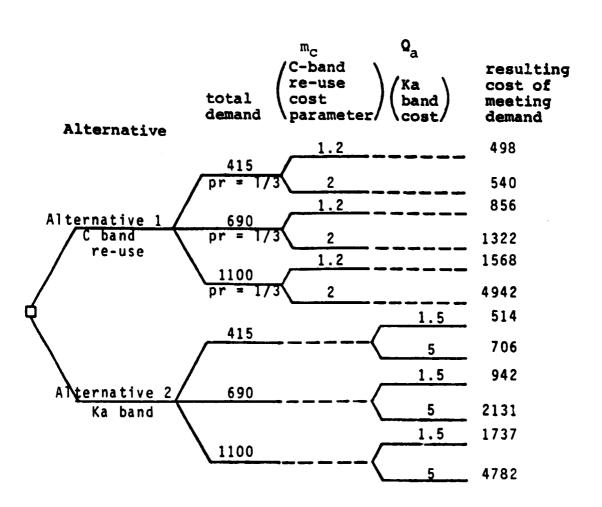
Fig. 11: Decision Tree for Cost Comparison

Section III

APPLICATION OF THE APPROACH TO COMMUNICATIONS
SATELLITE R&D DECISIONS

NASA faces a range of decisions in the area of communications satellite policy. The analysis presented here is focused primarily on the choice between Ka band technologies and re-use and conservation alternatives. The discussion here illustrated how a decision analysis approach can be used to address that question.

The analysis, however, intentionally leaves out many issues in order to illustrate analytical techniques. The full approach as outlined in Section I requires consideration of many other issues and much more attention to data, involvement of knowledgeable experts and decision makers, and structural modeling of satellite supply and demand. In addition, to be useful to NASA R&D planning, the focus of an analysis would have to be on the R&D allocation decisions that precede the technology deployment decisions.

Figure 12 illustrates the structure of an R&D decision analysis. This figure shows a two-stage decision tree for the R&D decision problem. In the first stage, R&D allocation decisions and R&D outcomes are represented. In the second stage the deployment decisions and outcomes are represented. The analysis of the second deployment stage would be similar to the analysis presented in the preceding section.
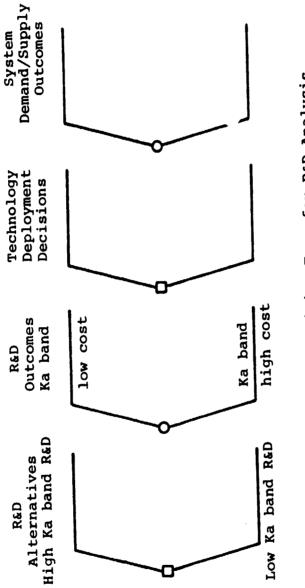
Fig. 12: Two-Stage Decision Tree for R&D Analysis

The analysis of the R&D stage would use the same
decision analysis techniques as illustrated in the preced-
ing section. The additional information requirements would
include information on the cost of each R&D alternative and
the probabilitites of various outcomes of the R&D.

Within this structure alternative NASA R&D programs
can be represented as alternatives. The value of an R&D
program would be characterized in terms of the change in
information produced by the program including delineation
of new technical alternatives. Numerical values for this
information could be imputed from the resulting changes
in deployment decisions and reduced costs or increased
level of communications services.

We have not carried out the detailed R&D analysis in
this paper. Such an analysis should properly be carried out
with the close involvement of the relevant technical special-
ists and NASA officials. This two-stage R&D decision analysis
structure when combined with appropriate structural models of
communications markets would provide significant insights to
NASA R&D planning and could serve as a basis for a rational
allocation of NASA communications satellite R&D funds.

Notes

1. Calio, Anthony J. Statement before the Subcommittee on Space Sciences and Applications, Committee on Science and Technology, U.S. House of Representatives, Feb. 20, 1979.

2. For a general introduction to decision analysis, see:
   Howard, R. A., "Decision Analysis: Applied Decision
       Theory,"
   North, D. W., "A Tutorial Introduction to Decision
       Analysis,"
   Howard, R.A., "The Foundations of Decision Analysis,"
   all reprinted in Readings in Decision Analysis,
   SRI International, 2nd ed., 1977.

3. See: Spetzler, C. S., and C. S. Stael von Holstein, "Probability Encoding in Decision Analysis," reprinted in Readings in Decision Analysis, SRI International, 2nd ed., 1977.

4. It may in fact be easier to re-use Ku band than C band, suggesting the alternative of re-using Ku but not C might be more realistic than the one presented here.

5. Re-use of the Ka band will likely use Ku band re-use technology, and therefore should be feasible.

APPENDIX A. Western Union Demand Data and
             Comparison to the ITT Data

Below we summarize the demand data from the Western

Union (WU) report and, where possible, compare it to the

ITT data. Western Union's demand model appears to be com-

prehensive, and fairly complex. It builds up a forecast

by aggregating data on a large number of telecommunications

services.

Table A-1 shows Western Union's forecast of net long

haul traffic for voice, data and video services for 1980,

1990, and 2000. A terrestrial/satellite cost model is then

used to split out satellite traffic from the total long haul

traffic. The estimate of satellite traffic appears in

Table A-2.

The data for the three types of services in the above

tables are each stated in different units. This makes com-

parisons between service types and with the ITT data difficult.

The data is eventually all converted into a common unit, equiv-

alent transponders. The process used to make the conversions

is not known at this point. There is some indication it is

a relatively complex process, and includes consideration of

peak hour demand, among other factors.

Western Union's resulting estimates of total long haul

traffic and satellite traffic in transponders are shown in

Tables A-3 and A-4. In each case we have shown the demand

is split between the three types of service. From these data,

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Table A-1: WU - Forecast of Annual Long Haul Traffic

	1980	1990	2000
Voice (1/2 circuits)	2,100,000	5,300,000	13,700,000
Data (terabits/year)	1,100	7,000	27,600
Video (widebond channels)	170	290	450

Table A-2: WU - Forecast of Satellite Demand

	1980	1990	2000
Voice (1/2 circuits)	345,000	892,000	2,905,000
Data (terabits/year)	464	3,215	14,533
Video (wideband channels)	79	187	340

Table A-3: WU - Total Long Haul Traffic in Transponders

	1980		1990		2000	
Voice	2100	(92%)	3407	(91%)	8828	(93%)
Data	13	(1%)	75	(2%)	320	(3%)
Video	176	(7%)	253	(7%)	357	(4%)
Total	2289	(100%)	3735	(100%)	9505	(100%)

Table A-4: WU - Satellite Demand in Transponders

	1980		1990		2000	
Voice	346	(80%)	360	(76%)	1862	(80%)
Data	61	(1%)	42	(5%)	201	(9%)
Video	80	(19%)	157	(19%)	258	(11%)
Total	432	(100%)	829	(100%)	2321	(100%)

Table A-5: WU - Satellite Capture Ratio (derived) in percent

	1980	1990	2000
Voice	16	18	21
Data	46	56	63
Video	´5	62	72

we are able to derive a satellite capture ratio, which is
shown in Table A-5.

It is interesting to compare data from the latter
three tables to the ITT data presented in Section 2. In
order to facilitate comparison, the relevant pieces of data
will be reproduced side-by-side.

Table A-6 compares the contractors' estimates of the
way total long haul traffic is split between the three types
of service. There is a major discrepancy over the importance
of data traffic. Although the difference could be attribut-
able to differing perceptions of what is going to happen
with respect to the various technologies, it is also possible
the discrepancy stems from the use of different accounting
conventions. The fact that the results are so different for
1980, essentially the present, supports the latter view. The
discrepancy will hopefully be resolved when the full reports
become available.

In Table A-7 the estimates of satellite capture ratio
are presented. The results are again very different in 1980,
but concur to a large degree in 1990 and 2000.

The estimates of satellite demand in transponders is
presented in Table A-8. The forecasts presented in Table A-8
are the product of the full analysis of each of the contractors,
and are therefore the most interesting data for comparison.
As can be observed, the forecasts are so different that one
questions whether they are based on the same set of basic

Table A-6:   ITT and WU - Comparison of Split of Total
             Long Haul Traffic Between Service Types - in percent

Format: (ITT data, WU data)

	1980	1990	2000
Voice	(74, 92)	(76, 91)	(77, 93)
Data	(15, 1)	(15, 2)	(12, 3)
Video	(11, 7)	(9, 7)	(11, 4)

Table A-7:   ITT and WU - Satellite Capture Ratio - in percent

Format: (ITT data, WU data)

	1980	1990	2000
Voice	(2, 16)	(15, 18)	(25, 21)
Data	(1, 46)	(50, 56)	(60, 63)
Video	(50, 45)	(60, 62)	(60,72)

assumptions and definitions. Although it is a major task
to critique either of the analyses and to improve them, one
apparent assumption of the WU analysis is that transponder
capacity remains constant at 50 MSPS. If the WU results
are recalculated with the increasing transponder capacities
used by ITT, the forecast for the total number of transponders,
as shown in Table A-9, is much closer to ITT's. This does
not mean one analysis is correct and the other is not, but at
least it offers one explanation for the discrepancies. We
note that there is still a major divergence in terms of the
split between voice, data and video traffic.

Table A-8:   ITT and WU - Demand for Transponders

Format: (ITT data, WU data)

	1980	1990	2000
Voice	(21, 346)	(225, 630)	(474, 1862)
Data	(5, 6)	(345, 42)	(436, 201)
Video	(35, 80)	(110, 157)	(211, 258)
Total	(61, 432)	(690, 829)	(1121, 2321)

Table A-9:   WU - Demand for Transponders, modified to include increasing transponder capacity (in 36 MHz equivalent transponders)

	1980	1990	2000
Voice	412	438	862
Data	7	29	93
Video	95	109	119
Total	514	576	1074

APPENDIX B.   The Probability Distributions for Demand
              for Voice, Data, and Video Services

The distributions are shown on the next three pages.

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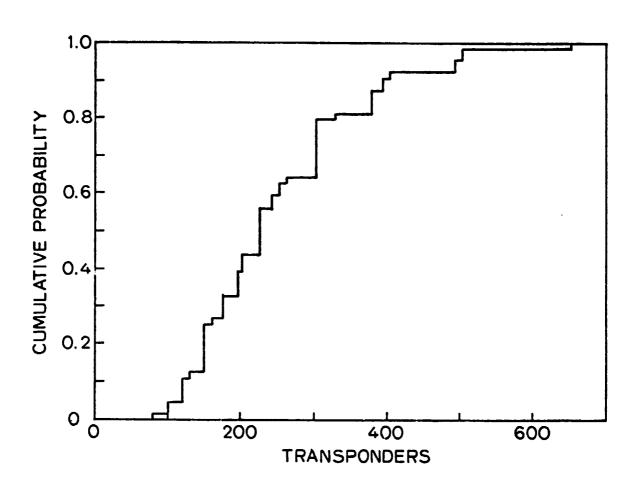
Fig. B-1: Cumulative Distribution on Voice Demand for Transponders

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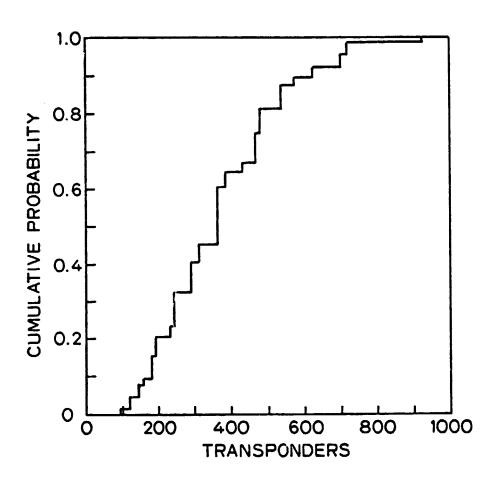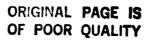
Fig. B-2:   Cumulative Distribution on Data Demand for Transponders

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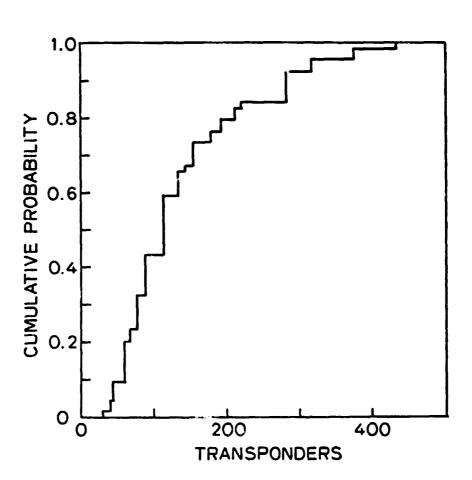
Fig. B-3:   Cumulative Distribution on Video Demand for Transponders

APPENDIX C. <u>Expanded Version of the Illustrative</u>
<u>Cost Comparison</u>

In Section 6 we presented an illustrative analysis
of the costs of Ka band service and C band re-use. This
appendix is an expanded version of that analysis: a third
technological alternative has been added. A full descrip-
tion of the cost calculations is also presented.

We compare three technological alternatives.

1. <u>C-band re-use</u>. The C band spectrum is re-used
    through a variety of technologies. The Ku band
    is used before re-use is employed on the C band.
    No re-use technologies are available for Ku band.
    The Ka band cannot be used.

2. <u>Ka band</u>. The Ka band can be used. No re-use is
    possible for the C band or the Ku band. In per-
    forming the analysis it was found that the
    capacity available from the use of all three
    bands often fell short of meeting demand. There-
    fore re-use of the Ka band only is allowed, say
    through the use of spot beams with on-board
    switching.

3. <u>Combination</u>. Both of the above are available. The
    minimum cost combination for each demand level
    will be used.

The decision tree for the analysis is shown in Figure
C-1. There are four state variables: total demand, system
capacity, cost of C-band re-use, and Ka system cost.

The total demand distribution from Figure 4 was approxi-
mated by three-branch distribution. In order to reduce the
amount of analytic effort required, we again use determinis-
tic values for system capacity. The values used are:

Technological
Alternative

Demand

System
Capacity

Cost of
C-band
Re-use

Ka System
Cost
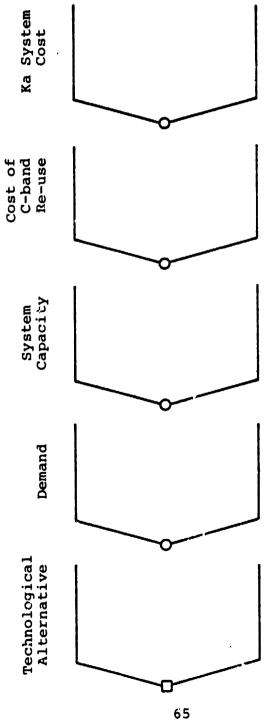
Fig. C-1: Tree for C band Re-use vs. Ka band Comparison

C   band: CAP_c = 216

Ku band: CAP_k = 144

Ka band: CAP_a = 288

Uncertainty on system capacity could be added to the analysis
with no change in the methodology used.

The basic unit of cost used is dollars per transponder.
We are interested only in relative costs. It is assumed the
costs for the C and Ku bands are certain, while Ka band cost
is uncertain. The following data is used:

Q_c = cost/transponder in C-band = \$1

Q_k = cost/transponder in Ku-band = \$1.50

Q_a = cost/transponder in Ka-band is described
         by the distribution:

$$\text{Prob} \left(Q_a = \$1.50 \right) = .5$$
$$\text{Prob} \left(Q_a = \$5.00 \right) = .5$$

A simple model of re-use cost is employed for C band re-use
(and for Ka band re-use when required). It is assumed re-use
technologies are added one at a time until demand is met.
Each technology allows the entire spectrum capacity to be
re-used; i.e. it doubles capacity. Cost increases for
each re-use, as follows:

Fig. C-2: Full Decision Tree

$$CRU(n) = Qm^n \qquad (2)$$

where:

CRU(n) = marginal cost per equivalent trans-
ponder when the spectrum is being used for the
nth time

Q = cost per transponder without re-use

m = a multiplier (m > 1)

n = number of times the spectrum is being
re-used

For Alternative 1, C-band re-use, the multiplier is
m_c , and is uncertain:

$$Prob\left(m_c = 1.2 \right) = .5$$
$$Prob\left(m_c = 2 \right) = .5$$

For cases where re-use is required for the Ka band, the
multiplier m_a is taken to have the value 1.2 .

Figure C-2 shows the full decision tree, with the
deterministic capacity variable removed. At the right side
of each final node in the tree is a resulting minimum
cost for meeting demand. The cost calculations are out-
lined below.

Cost Calculations - Alternative 1

Demand is met by first using C band, then the Ku band,
and then by re-using the C-band as many times (or fraction
of a time) as required. For the range of demand values
encountered here, the following equation can be used.

Let:

$$R = \frac{DT - CAP_k}{CAP_c}, \text{ where } DT \text{ is demand}$$

INT = largest integer less than R

f = R − INT

Then the total cost is given by:

$$COST = Q_c \cdot CAP_c \left[\sum_{i=o}^{INT-1} m_c^i + fm_c^{INT} \right] + Q_k \cdot CAP_k$$

The amount of re-use required to meet demand for each demand level is described in Table C-1. The resulting costs are shown on the right side of the tree in Figure C-2.

Cost Calculation - Alternative 2

Demand is met by first using the C, then the Ku, and then the Ka band, and then by re-using the Ka band if necessary. For the range of demand values encountered here, we use the following to calculate cost.

Let:

$$R = \frac{DT - CAP_c - CAP_k}{CAP_a}, \text{ where } DT \text{ is demand}$$

INT = largest integer less than R

f = R − INT

Total cost is:

C − 3

Table C-1: How Demand is Met

Alternative	Node Number from Figure 11	Technologies Used*
1	1	Use 19% of Ka band
	2	Use 19% of Ka band
	3	Use Ka band, then re-use 15% of it
	4	Use Ka band, then re-use 15% of it
	5	Use Ka band, then re-use it once, then re-use 57% of it
	6	Use Ka band, then re-use it once, then re-use 57% of it
2	7	Re-use 25% of C band
	8	Re-use 25% of C band
	9	Re-use C band, then re-use 53% of it
	10	Re-use C band, then re-use 53% of it
	11	Re-use C band three times, then re-use 43% of it
	12	Re-use C band three times, then re-use 43% pf it
3	13	Re-use 25% of C band
	14	Re-use 25% of C band
	15	Use 19% of Ka band
	16	Re-use 25% of C band
	17	Re-use C band, then re-use 53% of it
	18	Re-use C band, then re-use 53% of it
	19	Use Ka band, then re-use 15% of it
	20	Re-use C band, then re-use 53% of it
	21	Re-use C band twice, then use Ka, then re-use 9 % of C
	22	Re-use C three times, then re-use 43% of it
	23	Use Ka, re-use Ka, re-use 76% of C band
	24	Re-use C twice, use Ka, re-use 7% of Ka

*C band and Ku band are always used once before C band re-use or Ka band use.

$$\text{COST} = \text{CAP}_a \left[\sum_{i = o}^{\text{INT}-1} m_k^i + fm_k^{\text{int}} \right] + Q_c \cdot \text{CAP}_c + Q_k \cdot \text{CAP}_k$$

The amount of Ka band use required to meet demand for each demand level is shown in Table C-1. The resulting cost values appear in Figure C-2.

Cost Calculations - Alternative 3

Under Alternative 3, it is assumed demand is first met by using the C and Ku bands once. Additional capacity is added through re-use of the C-band and/or through the use and subsequent re-use of the Ka band. Capacity is added in increasing order of its marginal cost. This generates a supply curve for capacity. Table C-2a shows the increase in marginal cost as the C band is re-used, and as the Ka band is used and subsequently re-used. When the appropriate cost parameters are "plugged in," the supply curve is derived by combining the lists for the two technologies and selecting alternatives in order of increasing marginal cost. Since there are two possible values of Ka system cost and two possible values of C band re-use cost, a total of 4 supply curves were needed in order to calculate the costs at the end of the tree. The development of the supply curve for one set of parameters is shown in Table C-2b the resulting supply curve appears in Figure C-3. For a given demand value, total cost is the area under the supply curve out to

<u>Table C-2a</u>: Marginal Cost of Increased Capacity

C Band Re-use:

Increased Capacity in Transponders	Marginal Cost per Transponder
first 216	$m_c \, Q_c$
next 216	$m_c^2 \, Q_c$
next 216	$m_c^3 \, Q_c$
next 216	$m_c^4 \, Q_c$
.	.
.	.
.	.

Ka Band Introduction and Subsequent Re-use:

Increased Capacity in Transponders	Marginal Cost per Transponder
first 288 (introduction)	Q_a
next 288 (first re-use)	$m_a \, Q_a$
next 288	$m_a \, Q_a$
next 288	$m_a^2 \, Q_a$
next 288	$m_a^3 \, Q_a$
.	.
.	.
.	.

Table **C-2b**:   Development of the Supply Curve for
                   One Set of Cost Parameters

Parameters: $m_c = 1.2$, $Q_a = 1.5$, $m_a = 1.2$

C Band:

Increased Capacity in Transponders	Marginal Cost per Transponder
first 216	1.20
next 216	1.44
next 216	1.73
next 216	2.07
.	.
.	.
.	.
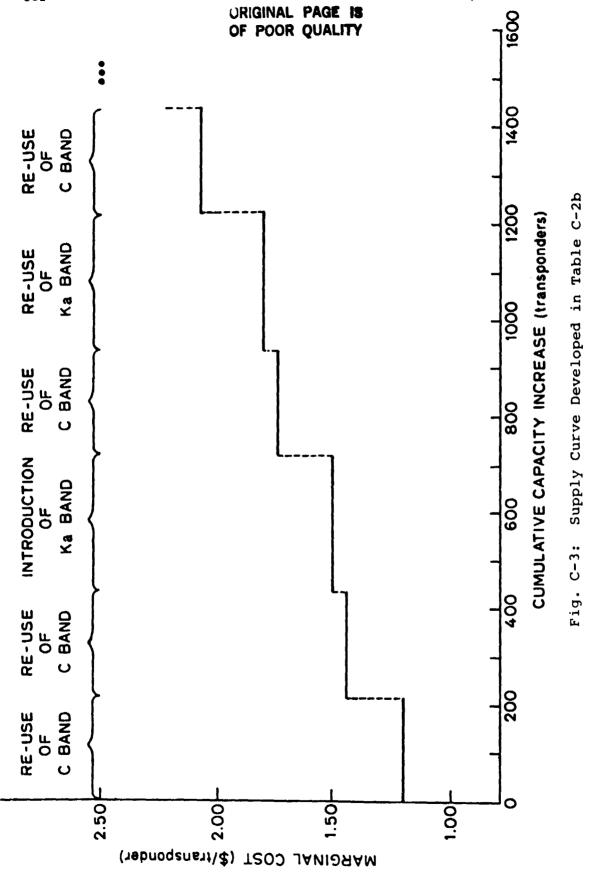
Ka Band:

Increased Capacity in Transponders	Marginal Cost per Transponder
first 288	1.50
next 288	1.80
next 288	2.16
next 288	2.59
.	.
.	.
.	.

Resulting Supply Curve:

Increased Capacity in Transponders	Cumulative Capacity Increase	Marginal Cost Per Transponder
first 216	216	1.20
next 217	432	1.44
next 288	720	1.50
next 216	936	1.73
next 288	1224	1.80
next 216	1440	2.07

Fig. C-3: Supply Curve Developed in Table C-2b

the demand value. Table C-1 shows how demand was met for
each of the branches of the decision tree pertaining to
Alternative 3.

Results

Because the data used here is illustrative, no defini-
tive statements can be made from the results. However, it
is interesting to analyze the tree in Figure C-2 both
quantitatively and qualitatively.

The tree can be rolled back to yield an expected cost
of meeting demand for each alternative. The results are:

Alternative 1, (C-band re-use): Expected cost = $1621

Alternative 2, (Ka band): Expected Cost = $1802

Alternative 3, (Combination): Expected Cost = $1171

If Research Programs 1, 2, and 3 were available that
led respectively to Alternatives 1, 2, and 3 being available
in 1990, then it appears that Program 3 leads to a savings
of $450 compared to Program 1, and a savings of $631 compared
to Program 2. If the costs of the research program were
available, the net savings generated could be compared.

In Section II, comparing the full distribution on
total demand to the distribution on total capacity led to
the conclusion that there is a probability of .86 that
demand will exceed capacity if neither re-use or Ka band
are available. In the cruder analysis here, we see from

Table C-1 that in no case can demand be met by just the C
and Ku bands without re-use. In the case of the lowest
demand value, 415 transponders, demand is met either by
using 19% of the Ka band or by re-using 25% of the C band.
For the higher demand levels of 690 and 1100 transponders,
the introduction of the Ka band without re-use is not
sufficient to meet demand. It appears likely that re-use
will be required by 1990. At the highest demand level,
extensive re-use is necessary. We also note that the
lowest cost "solutions" involve mixing re-use of the C and
Ka bands.

COST COMPARISON OF COMPETING LOCAL DISTRIBUTION SYSTEMS
FOR COMMUNICATION SATELLITE TRAFFIC

Frederick E. Dopfel
October 1979

Abstract

The purpose of this paper is to describe the boundaries of market areas which favor various means for distributing communications satellite traffic. The distribution methods considered are: (1) central earth station with cable access, (2) rooftop earth stations, (3) earth station with radio access, and (4) various combinations of these methods.

The method of comparison is to determine the least cost system for a hypothetical region described by number of users and the average cable access mileage. The region is also characterized by a function which expresses the distribution of users.

The results indicate that the least cost distribution technology is a central earth station with cable access for medium to high density areas of a region, combined with rooftop earth stations or (for higher volumes) radio access for remote users.

COST COMPARISON OF COMPETING
LOCAL DISTRIBUTION SYSTEMS
FOR COMMUNICATION
SATELLITE TRAFFIC

Frederick E. Dopfel

Report No. 26
October 1979

PROGRAM IN INFORMATION POLICY

Engineering-Economic Systems Department
Stanford University   Stanford, California 94305

Abstract

The purpose of this paper is to describe the boundaries of market areas which favor various means for distributing communications satellite traffic. The distribution methods considered are: control earth station with cable access, rooftop earth stations, earth station with radio access, and various combinations of these methods.

The method of comparison is to determine the least cost system for a hypothetical region described by number of users and the average cable access mileage. The region is also characterized by a function which expresses the distribution of users.

The results indicate that the least cost distribution is central earth station with cable access for medium to high density areas of a region, combined with rooftop earth stations or (for higher volumes) radio access for remote users.

Introduction

Technological improvements increasing satellite capacity and lowering costs are likely to continue, implying that the long haul portion of telecommunications costs will steadily assume less importance. This paper focuses on least cost configurations for local distribution of satellite traffic, which is likely to account for an ever increasing portion of telecommunications cost.

The local distribution problem is non-trivial because of the different approaches and technical alternatives for meeting demand that are available. In general, existing common carriers favor use of large earth stations and local distribution provided by existing facilities. Current plans call for only five Western Union earth stations and only seven joint AT&T/GTE earth stations. New entrants, on the other hand, prefer to avoid distribution over existing facilities, instead relying on smaller units which can be placed on customer premises. The latter approach is exemplified by the Satellite Business Systems (SBS) proposal for small rooftop earth stations. In the SBS case, the local distribution cost is insensitive to distance. An alternative approach, the Xerox Telecommunications Network (XTEN) employs an MDS (radio) system for local distribution. The XTEN system's distribution cost is basically independent of distance, although reception is limited to points within about forty miles of the transmitter.

The presence of the three technical alternatives poses
questions about how local distribution should be accomplished.
Demographic characteristics of the region served will usually
determine which system has the least cost. However, the best
means of local distribution could be a combination of the com-
peting technical arrangements.

Cost Characteristics for an Example Service

For the purposes of this discussion, an example service
is taken from a teleconferencing study.[*] The service provides
four channels for one-way video and two-way audio communications.
The study, which reached the now familiar conclusion that satel-
lite systems are often the most cost-effective way to provide
long distance communications, provides cost estimates for earth
stations, cable distribution, and an MDS-type system. Cost
equations extracted from this report are used (with simplifi-
cation) in this paper to provide order of magnitude estimates.
The cost structure for a region with n users is:

earth station with cable access (C)

$$c = c_1 + c_2 rn$$

rooftop earth stations (ES)

$$c = c_3 n$$

earth station with MDS system (MDS)

$$c = c_1 + c_4 + c_5 n$$

---

[*] Teleconferencing: Cost Optimization for Satellite and Ground
Systems for Continuing Professional Education and Medical Services,
D. Dunn, B. Lusignan, E. Parker, Stanford University, May 1972.

where:

c_1 = cost of earth station equipped for redistribution (11,500)

c_2 = cost per mile per user for cable distribution (6,000)

c_3 = rooftop earth station cost (9,200)

c_4 = cost of MDS transmitter (86,000)

c_5 = cost of user MDS receiver (8,600)

r = average mileage for cable distribution per user.

Figures in parentheses are approximate dollar costs for installed

equipment and maintenance. Note that different types of

systems may have different space segment designs for minimum

cost operation.

C vs ES vs MDS

The minimum cost arrangements for regions described by the

variables r and n are now examined. If only one technical

arrangement can be used for a region, the transitions occur at:

ES-MDS tradeoff

$$n = \frac{c_1 + c_4}{c_3 - c_5} = 162.5 \text{ (receivers)}$$

C-MDS tradeoff

$$r = \frac{c_5}{c_2} + \frac{c_4}{c_2} \frac{1}{n} = 1.4\overline{3} + \frac{14.\overline{3}}{n} \text{ (miles)}$$

C-ES tradeoff

$$r = \frac{c_3}{c_2} - \frac{c_1}{c_2} \frac{1}{n} = 1.5\overline{3} - \frac{1.91\overline{6}}{n} \text{ (miles)}$$

The boundaries of these areas are plotted in Exhibits 1-A, B, C.

Exhibit 1-D displays the composite of these boundaries. The

C-MDS, C-ES, and ES-MDS boundaries intersect at a common point.
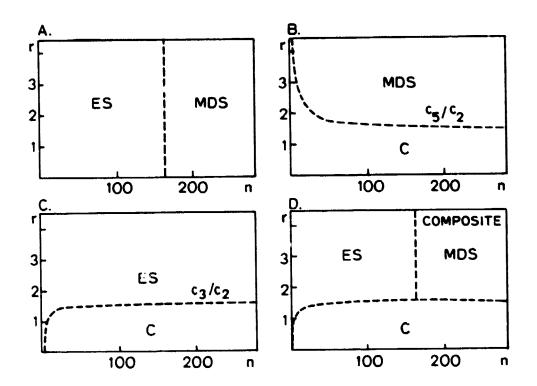
Exhibit 1

Using the above cost estimates, this intersection point is at

r = 1.522 and n = 162.5.

The conclusion in this case is fairly straightforward. If

the demand is highly concentrated, a central earth station ac-

cessed by cable is the lowest cost alternative, regardless of

the number of users in the region. If the demand is low density

(geographically dispersed), then either an MDS system or rooftop

earth stations dominate in terms of cost. The choice between

these latter two depends only on the number of users, provided

users are not so widely dispersed as to be outside the range of

the MDS transmitter. Higher demand favors the MDS system, since

the incremental cost of an MDS receiver is slightly less than

the cost of an individual earth station (an MDS distribution

system has a fixed cost as well). However, if earth station

costs become low enough, the MDS system will not be a least

cost alternative in any region.

C vs C and ES

It is sometimes possible, when the space segment allows

compatible designs of two local distribution technologies, to

assume that more than one technology will be used in the same

system. For example, consider the joint use of cable and roof-

top earth stations. Given the cost characteristics of these

systems, it seems that distribution cost would be minimized

by employing cable for the nearby users and rooftop earth

stations for the more remote users.

Unfortunately, the boundary separating near and remote areas

is not well defined by r and n alone. More information about

5

the demography of the region is required. Specifically, we need to know the number of users n within a given radius r of the cable relay station. This information, which can be represented by a function of radius $n(r)$, is sufficient for us to obtain a second function, $r(n)$, which tells how average cable mileage changes as additional users are served.

For regions of interest, we will assume that all users can be ordered so that $s(n)$, the <u>increment</u> in cable-miles required to serve the n th user, is non-decreasing. This is a useful concept since it enables an evaluation of the incremental cost of serving the n th user by alternative arrangements. If served by cable, the incremental cost is $c_2 s(n)$. If served by rooftop earth station, the incremental cost is c_4. This allows a division of users by the distribution technique serving them:

$$\text{Let} \quad \bar{n} = \max \ \{n \,|\, s(n) \leq c_3/c_2\}$$

then use:

$$\text{C for users} \quad 1, 2, \ldots \bar{n}$$

$$\text{ES for users} \quad \bar{n} + 1, \bar{n} + 2, \ldots n$$

Note that if $s(n)$ is not non-decreasing, a more complicated analysis is required. Furthermore, this analysis could indicate that a second central earth station accessed by cable is required to minimize distribution cost--a result that is precluded when $s(n)$ is non-decreasing.

It can be shown that $s(n)$ and $r(n)$ are related:

$$s(n) = r(n) + nr'(n)*$$

---

* The total number of cable-miles is $nr(n)$, the number of users multiplied by their average distance from the transmitter. The increment in cable-miles $s(n)$ is just the rate of change with respect to n of total cable-miles--the derivative of $s(n)$ with respect to n.

This relation can be used to plot an appropriate boundary for "C only" and "C and MDS" in our $r - n$ space diagrams for various assumed "demographies" $s(n)$. For example, suppose that regions of interest have users distributed such that $s(n)$ is linear:

$$s(n) = an \qquad \text{for some constant } a,$$

so that $r(n) = \dfrac{an}{2}$ and $s(n) = 2r(n)$.

$s(n)$ reaches the criterion c_3/c_2 at $\bar{r} = \dfrac{c_3}{2c_2}$ and $\bar{n} = \dfrac{c_3}{ac_2}$.

Note that for this special case, $\bar{r}$ does not depend on n. This example is depicted in Exhibit 2-A. As shown, for _any_ linear demography, there is a threshold value above which both cable and rooftop earth stations are used jointly. This threshold is one-half the value of the threshold (in the limit) in Exhibit 1-C.

To show that the boundary is not always flat, consider a logarithmic demography defined by:

$$s(n) = a(1 + \log n) \text{ for some constant } a$$

so that $r(n) = a \log n$.
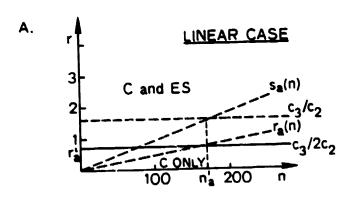
$s(n)$ reaches the criterion c_3/c_2 at $\bar{n} = e^{1 + \frac{c_3}{ac_2}}$ and $\bar{r} = \dfrac{c_3}{c_2} - a$.

The resulting boundary is $\log n = \dfrac{rc_2}{c_3 - rc_2}$ or $n = \exp\left[\dfrac{rc_2}{c_3 - rc_2}\right]$.

This example is depicted in Exhibit 2-B.

It is important in the examples above to note that the boundary of the areas "C only" and "C and ES" is not invariant to the demographic "class" of the region. Even in the limit for a

A. LINEAR CASE

B. Log CASE
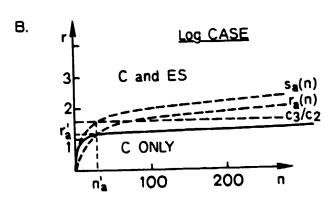
Exhibit 2

large number of users, the threshold for introduction of user

earth stations depends on the type of demography assumed. For

most regions of interest, the boundary is expected to be fairly

flat as shown in the examples.

C vs C and MDS

Now consider the joint use of cable and an MDS system. This

analysis proceeds parallel to the above analysis, except that it

is slightly complicated by the presence of a fixed cost for the

MDS transmitter. Otherwise, the MDS system has cost characteris-

tics similar to rooftop earth stations. In the previous case, the

behavior of $s(n)$ after it reaches the cost criterion was irrelevant

as long as it was non-decreasing; in this case, it matters.

If the systems are used jointly, cable access will be em-

ployed for nearby users and MDS receivers for remote users. The

users may be divided by the criterion:

$$\text{let } n^* = \max \ \{n \mid s(n) \overset{<}{-} c_5/c_2\}$$

then use

$$\text{C for users} \quad 1, \ 2, \ \ldots n^*$$

$$\text{MDS for users} \quad n^* + 1, \ n^* + 2, \ ..n \ .$$

The system will be used jointly only if:

$$\text{Cost (C only)} \quad ` \quad \text{Cost (C and MDS)}$$

$$\text{or}$$

$$c_1 + c_2 rn \quad ` \quad c_1 + c_2 r(n^*)n^* + c_4 + c_5(n-n^*)$$

$$\text{or}$$

$$n \quad ` \quad \frac{c_4 + (c_2 r(n^*) - c_5)n^*}{c_2 r - c_5}$$

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Consider again the linear demography $s(n) = an$ and $r(n) = \frac{an}{2}$. Transition occurs at $n^* = \frac{nc_5}{2rc_2}$ $\quad r^* = \frac{c_5}{2c_2}$. The condition on n requires:

$$c_1 + c_2 rn > c_1 + c_2 \frac{c_5}{2c_2} \frac{n}{2r} \frac{c_5}{c_2} + c_4 + c_5(n - \frac{nc_5}{2rc_2})$$

or

$$n > \frac{\frac{c_4}{c_2} r}{(r - \frac{c_5}{2c_2})^2} \quad \left[\text{for } r > \frac{c_5}{2c_2} \right]$$

Exhibit 3-A displays the boundary for the linear demography. Note that this curve is always below the curve in Exhibit 1-B, which assumed that the systems could not be used jointly.

C vs C and ES vs C and MDS

Now let's consider the case where cable is used and either MDS or user earth stations can be used in addition. The linear demography $s(n) = an$, $r(n) = \frac{an}{2}$ is assumed again. To determine the boundary, note that:

$$\text{Cost (C and ES)} > \text{Cost (C and MDS)}$$

$$\implies c_1 + c_2 r(\bar{n})\bar{n} + c_3(n - \bar{n}) > c_1 + c_2 r(n^*)n^* + c_4 + c_5(n - n^*)$$

$$\implies c_2 \frac{c_3}{2c_2} \frac{nc_3}{2rc_2} + c_3(n - \frac{nc_3}{2rc_2}) > c_4 + c_2 \frac{c_5}{2c_2} \frac{nc_5}{2rc_2} + c_5(n - \frac{nc_5}{2rc_2})$$

$$\implies n > \frac{4rc_2 c_4}{c_5{}^2 - c_3{}^2} + 4rc_2(c_3 - c_5)$$

In the limit on r, $\quad n = \frac{c_4}{c_3 - c_5} = 143$

A.   LINEAR CASE

C and MDS

C ONLY

$c_5/2c_2$

B.   LINEAR CASE -
                                                        COMPOSITE

C and ES

C and MDS

C ONLY

Exhibit 3

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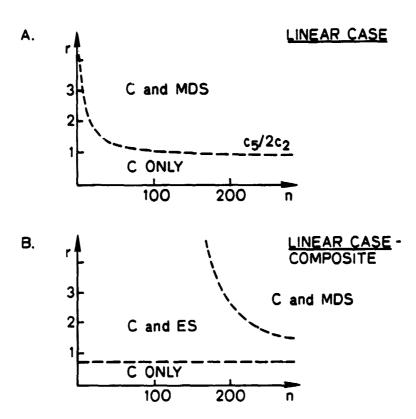
Note that the fixed cost for a central earth station does not enter in the boundary relation since both systems require it. This result is depicted in Exhibit 3-B, and represents the composite boundaries for the linear demography. Compare this figure to Exhibit 1-D, where it was assumed that only one system could be used in a region.

Remarks

In this paper, a technique has been described that can be used to determine the demographic characteristics of regions which favor different technical arrangements for local distribution of satellite traffic. The example used finds the least cost arrangement to be a central earth station with cable access for medium to high density areas of a region, combined with rooftop earth stations or MDS for more remote users in the region. The rooftop earth station--MDS tradeoff is decided principally by volume, with the latter arrangement preferred for high volumes. More analysis is required to support this finding for more general demographies.
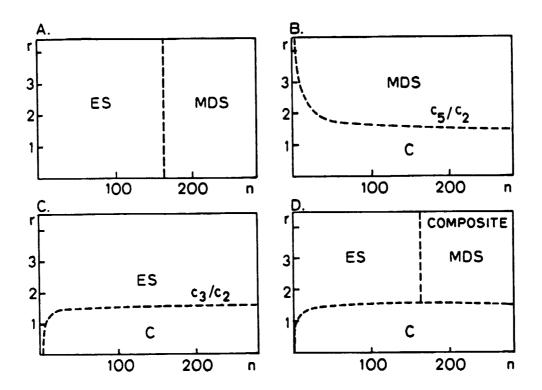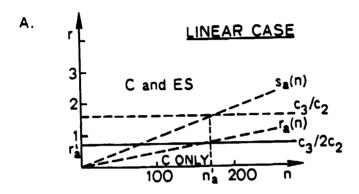
Exhibit 1

Exhibit 2

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A.   <u>LINEAR CASE</u>

B.   <u>LINEAR CASE</u> -
                                                COMPOSITE

Exhibit 3
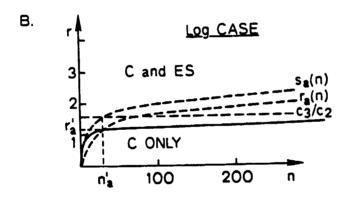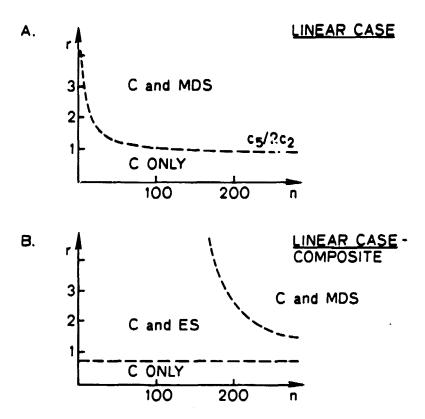
THE INITIAL COST OF
LOCAL RURAL TELEPHONE SERVICE

Carson E. Agnew
October 1981

Abstract

This paper reports a study of the investment cost of serving a rural telephone subscriber in the United States. In particular, this working paper presents estimates of the incremental investment cost per rural subscriber. There have been a number of previous studies of the costs of telephone service, most of them based on engineering data and a few using econometric techniques. A second purpose of this working paper is to survey some of the more recent of these studies.

Our analysis shows several things about rural equipment costs. Perhaps the most significant is that our econometric equation, as well as the majority of the engineering studies consulted, indicate that adding a rural subscriber costs about $500 in constant 1972 dollars. This is less than the conventional estimates of about $1000 per main station often heard in the industry, and is also less than the average increase in book value for REA borrowers, $940 in 1972 dollars.

THE INITIAL COST OF
LOCAL RURAL TELEPHONE SERVICE

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Report No. 35

October 1981

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1.   INTRODUCTION

This working paper reports a study of the investment cost of serving a rural telephone subscriber in the United States. It is part of a larger study concerned with the prospects and costs of new technologies and services for rural telecommunications. In particular, this working paper estimates a simple cost function that provides an estimate of the incremental investment cost per rural subscriber.

There have been a number of previous studies of the costs of telephone service, most of them based on engineering data and a few using econometric techniques. A second purpose of this working paper is to survey some of the more recent of these studies.

This is probably a good time to examine the cost of rural service. Although other studies[1] have addressed the prospects for introducing new technology providing both narrow band (e.g., voice bandwidth) and broad band (e.g., television bandwidth) services to rural areas, no such new technologies have yet been implemented in the U.S except experimentally. However, forces are now at work which seem likely to favor this new technology. This is because, at present, the local telephone company is the principal provider of telecommunications services to rural areas, and the pattern of telephone regulation has been such that the pricing of service has not been based on cost. The Rural Electrification Administration (REA) has subsidized the construction of rural telephone systems for many years through loans and loan guarantees with interest rates as low as two percent

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[1] For example: Office of Technology Assessment (1976), Alleman et al., (1977a), and BNR Inc. (1978).

per year. Perhaps more importantly, the telephone separations and settle-
ments process appears to have caused long distance and urban services to
subsidize local rural service, especially residencial service.

This subsidization of rural service may have suppressed innovation in
rural telephony. Innovation will be suppressed if the cost of rural service
per additional main station using a new technology is below the cost per
main station using existing technology, while the price of the service to
rural subscribers is below its economic cost by at least as large an
amount. To determine whether or not this is the case, one obviously needs
reliable estimates of the economic cost per new main telephone, which this
paper is intended to provide.

Such an estimate is also useful because any subsidization of local
rural telephone service is likely to be reduced by the deregulation of other
parts of the telephone industry. Factors such as introduction of competi-
tion in the markets for customer premises equipment (CPE) and private line
service, and the reselling of message toll service, will tend to eliminate
the financial resources providing the subsidy. Thus, it seems likely that
the revenues from local service will have to become more closely connected
to the cost of the service, possibly favoring the introduction of econom-
ically beneficial new technologies. If, as a matter of national policy, it
is determined that some new form of subsidy is appropriate, the estimates
provided here will give some idea of the size of the subsidy.

Our analysis shows several things about rural equipment costs. Perhaps
the most significant is that our econometric equation, as well as the
majority of the engineering studies consulted, indicate that adding a rural

subscriber costs about $500 in constant 1972 dollars. This cost includes

the equipment on the subscribers premises, the local loop and the incre-

mental costs of local switching. It does not include any additional costs

associated with the subscriber's use of the long distance telephone network.

The value of $500 per subscriber is less than the conventional estimate

of about $1000 per main station often heard in the industry, and is also

less than the average increase in book value for REA borrowers, $940 in 1972

dollars. That is, our econometric equation indicates a "fixed" or

"constant" cost component, equal to about $160 thousand in 1972, per REA

borrower. This component is not associated with several factors which could

influence costs, namely:

1.   Increases in the number of central offices,

2.   Decreases in the average length of haul for subscriber loops, or

3.   Changes from multi-party to one-party service during the period

      from which the data used in this study are drawn.

Although the lack of association is not water-tight because we had only

twenty years or so of data available, it appears that some of a typical REA

borrower's capital costs are incurred independently of increases in the

number of subscribers. One explanation for this may be that these costs are

somehow associated with network components not included in our $500

estimate, particularly the costs of toll connecting trunks used to link the

local central office to the toll network. To the extent that this explana-

tion is valid the long run cost of an additional subscriber will be closer

to $1000 than to $500. However, since the technologies proposed for as

substitutes for wire conventional telephones do not always affect the costs

of long distance service, the lower figure is still useful as a benchmark.

Finally, as noted in Section 2, several factors may cause a rural company to build an excessively capital-intensive plant. These factors all distort prices faced by a rural company from the market prices at which judgments of social costs should be made. Consequently the cost estimates reported here are not appropriate for assessng the social cost of rural telephone service. However, to the extent that these factors (which are primarily due to regulation) persist, the estimates can be used as benchmarks. Moreover, if deregulation eliminates these distortions the capital costs for rural companies will rise, and our estimates will be too low. Hence any new technology that appears favorable using the estimates presented here will seem even more attractive in a de-regulated environment.

2.   DEFINITION OF LOCAL RURAL SERVICE

This section outlines the components of local telephone service, and

discusses the nature of the problem of estimating the costs of providing

such service. Figure 1 shows schematically the elements of equipment that

go towards providing local telephone service. Some terminology used in this

paper is also illustrated in the figure.

Although there are many ways to divide the costs of the elements shown

in Figure 1, we have used the following four-way breakdown:[2]

1.   Station equipment, including inside wiring, station

      protectors and connectors.

2.   The "local loop," including the house drop and the distribu-

      tion cables connecting the subscriber's premises with the

      central office.

3.   Central office line and switching equipment.

4.   Toll and/or tandem connecting trunks, and other equipment

      needed to connect the local (Class 5) central office with the

      long-distance telephone network.

The first three items, taken together, represent essentially all the costs

of the local exchange network, connecting subscribers to one another by

means of a central switch. Although some newer technologies can be used to

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[2] For other taxonomies, see ITU (1972) and Hall (1975).
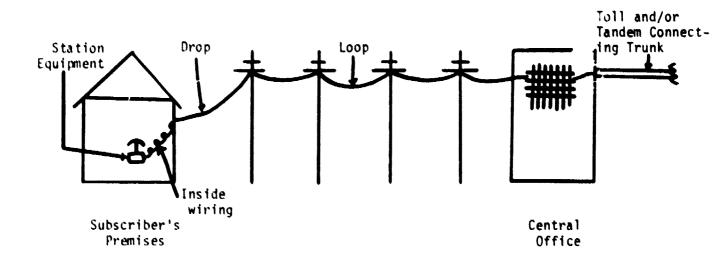
Figure 1.   Local Telephone Network Elements

move some of these switching functions to concentrator devices (thereby
reducing the number of very costly long loops), the general layout of the
local network is a "star" configuration in which all subscribers are
electrically connected to the central office. The fourth item is
essentially the cost of connecting this star network to the national toll
telephone network, carrying long haul traffic.[3]

2.1   Characteristics of Local Exchange Areas

There have been a number of studies of the characteristics of different
exchange areas; some of them are summarized in Alleman (1977b). Table 1 is
taken from a Bell System reference (Bell Telephone Laboratories, 1977) that
describes the basic parameters of wire centers in the public telephone net-
work. The most striking difference between the urban, suburban and rural
exchanges is the density of subscribers. Rural subscriber densities, with
which we are concerned with here, are about 5 working lines per square
mile.[4]

However, the Bell System values shown in Table 1 may overestimate the
density of rural areas, since the Bell System provides local service mostly
to urban and suburban areas. For example, Table 2 shows the typical dis-
tance from a central office to the main station for the Bell System, General
Telephone (GTE), and REA borrowers. As can be seen, Bell and GTE

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[3] In an urban setting it would be necessary to consider the role of tandem
switching machines. These are not very important in a rural setting.

[4] Alaska is, of course, still more sparely populated. For information on
the costs of service in Alaska see Hills and Morgan (1981).

Table 1

AVERAGE WIRE-CENTER PARAMETERS

FOR THE PUBLIC TELEPHONE NETWORK

Parameter	Urban	Suburban	Rural
Number of Entities	2.3	1.3	1.0
Area Served (sq.mi.)	12	110	130
CCS/MS*	3.1	2.7	2.1
Intra-office calling	31%	54%	66%
Working Lines	41,000	11,000	700
Working Lines/Sq.Mi.	3,417	100	5.4
Trunks	5,000	700	35
Trunk Groups	600	100	5

* Hundred call seconds per main station

Source: Bell Telephone Laboratories (1977).

statistics do not differ greatly, but the REA borrowers have substantially

longer loops, particularly the few very long loops.

Table 2

TYPICAL ROUTE DISTANCE FROM CENTRAL OFFICE TO MAIN STATION (MILES)
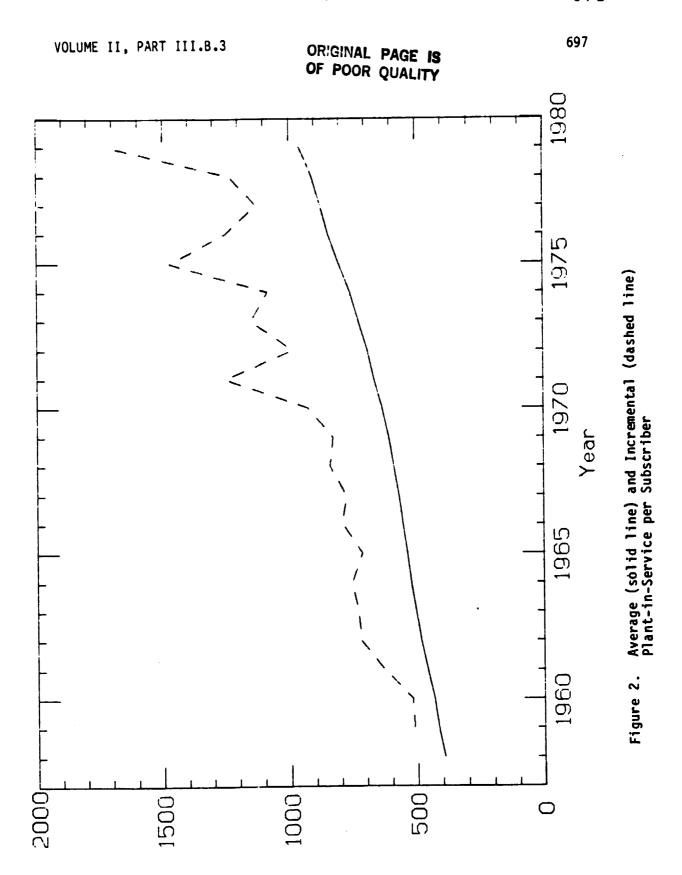
Organization	Mean	Median	Ninetieth Percentile
Bell System	2.0	1.5	3.5
GTE	2.2	1.5	4.5
REA borrowers	3.4	1.9	8.5

Sources: Lally and Hitt (1966)
          Davis and Lally (1971).

These few long loops have a significant cost impact. The most

startling statistics come from a 1964 survey of Bell System loops, which

showed that 1.5 million, or 3.25 percent of all Bell System customers, were

served by loops exceeding 30 kilofeet in length. These 3.25 percent of

customers used only 1.7 percent of the working Bell System loops (due to

multi-party lines), but accounted for 11.2% of total outside plant invest-

ment in the Bell System (Bell Telephone Laboratories, 1977)

2.2 Cost Trends in Rural Telephone Plant

The initial evidence we examine on rural subscriber costs is provided

by data published by its REA Annual Statistical Report. Figure 2 shows the

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Figure 2. Average (solid line) and Incremental (dashed line)
Plant-in-Service per Subscriber

trend in plant costs per subscriber in two different ways. The solid line is
the gross value of telephone plant-in-service for all REA borrowers, divided
by the number of subscribers. The dashed line shows the annual first differ-
ence of the plant-in-service account divided by the first difference of the
number of subscribers.[5] This quantity is an indication of the incremental
cost of plant per added subscriber.
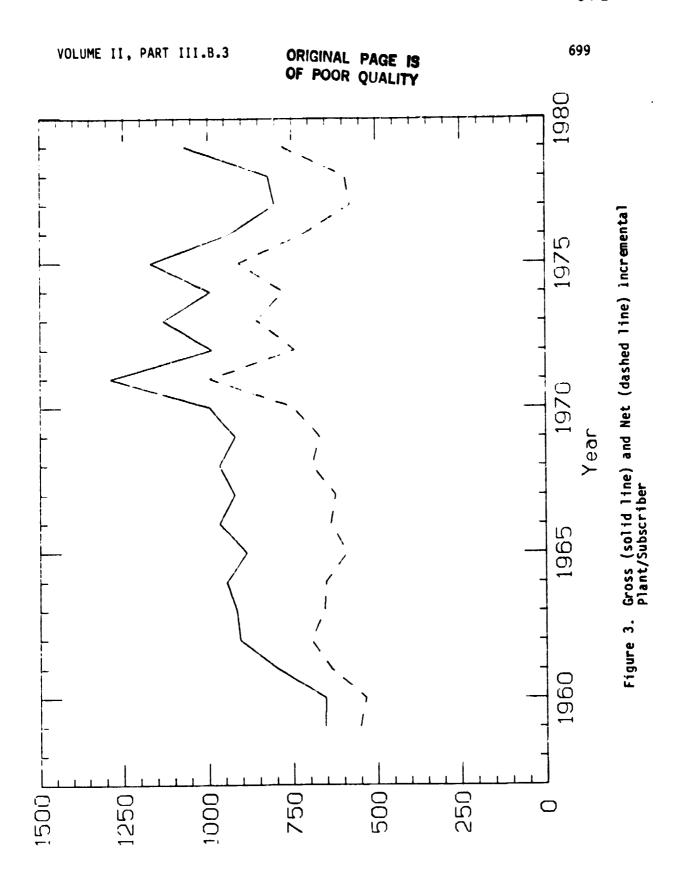
Neither of these figures has been been adjusted for inflation. Figure 3
presents some of this data with an inflation adjustment, based on the plant-
and-equipment component of the GNP deflator (Council of Economic Advisors,
1981). The solid line in this figure is the deflated value of the dashed
line in Figure 2. That is, it is the deflated difference in gross plant
divided by the difference in subscribers. The dashed line in Figure 2 is
based on the net plant-in-service, i.e., telephone plant-in-service less the
associated depreciation reserve. As can be seen in Figure 3, there has been
no discernable trend in the real incremental cost per subscriber for REA
borrowers. Table 3 shows the averages these two time series.

Table 3

AVERAGE COSTS PER NEW SUBSCRIBER
REA BORROWERS, 1958-79
(1972 dollars)

	Mean
Annual Change in Gross Plant-in-Service per Added Subscriber	$ 940
Annual Change in Net Plant-in-Service per Added Subscriber	697

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[5] See Appendix A for these data, and other series referred to below.

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Figure 3. Gross (solid line) and Net (dashed line) Incremental
Plant/Subscriber

1972 Dollars per Subscriber

2.3 <u>Significance of Book Costs</u>

As noted in the introduction, rural companies receive several subsidies. Because these subsidies distort the prices faced by rural companies, it can be shown that the companies have incentives to build and operate telephone systems which are not least cost when evaluated at the prevailing market prices. Consequently, the cost estimates based on book costs are not necessarily unbiased estimates of the social costs of serving a rural subscriber.

Three sources of bias can be identified for rural companies who are REA borrowers.

1. The low interest rates on REA loans and loan guarantees,

2. The general effect of rate-of-return regulation, and

3. The effect of toll settlements.

The first two factors (the REA interest rate subsidy and the so-called Averch-Johnson effect of rate of return regulation) should bias the typical REA borrower in favor of building a system which is too capital intensive. This is because both these factors make capital expenditures appear less costly to the firm than expenditures on operating cost items.[6]

The toll settlements process also produces a capital-intensive bias. To see why this is so, consider the following simplified model of the separations procedure. (See Gabel [1967] for a description of the procedure.)

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[6] Another and more subtle reason for a capital intensive bias may be the process by which REA sets the standards its borrowers must meet. Representatives of rural telephone companies and telephone equipment manufacturers play a role on the technical committees which affect how the standards are written. Both groups have an interest in making it possible to build plant which is too capital intensive.

A local company which is unaffiliated with a company providing toll service may be thought of as offering subscribers two different services: (a) local calling, and (b) access to the long distance network. However, these services are provided using the same equipment. The local company charges its subscribers for access to the network itself, and for local calling activity, although in most cases the price of local calling is set at zero. In addition, the local company acts as a collection agent for the "partnership" of companies which together provide end-to-end long distance service. (On any one call, there will be at least two local companies and a long distance company involved.)

The local company's share of the revenue of each toll call is not, however, fixed. Instead, it is determined through the separations and settlements algorithm, which is designed to recover a proportion of the local company's investment in whatever plant provides both local and long distance service. (Any costs directly attributable to long distance also are recovered.) The share of joint costs recovered from long distance charges depends on the relative use of local and long distance calling according to a complicated formula. As a result, either an increase in long distance callng or an increase the book value of jointly used plant increases the revenues of the local company.

Put differently, building excessively costly plant increases the revenue requirement, but some of this requirement will be returned through settlements more or less automatically. (If the additional investment increases the use of long distance service, so much the better.)

Thus, we see that the separations and settlements process probably also provides a capital-intensive bias in our estimates. As noted, this means that the estimates such as those presented in Section 4 below may understate the social costs of connecting a subscriber. This means that any new technology that appears favorable using the estimate presented below will be even more attractive if deregulation eliminates the intentives just discussed.

1.   PRIOR STUDIES OF LOCAL SERVICE COSTS

As noted in the introduction, there have been a number of previous studies of local exchange costs. The early studies are surveyed by Alleman (1977b), and will not be re-surveyed here. Alleman also discusses the so-called "cost of service" studies made by the Bell System during the 1960's and early 1970's, according to various cost study methodologies such as "fully distributed" cost, or "embedded direct cost." Most of these studies were used for rate making purposes, and were severely criticized for their data, assumptions, and overall approach. All tended to show residential service to be heavily subsidized by long distance and vertical services, but they did not deal specifically with rural telephone service.

Those studies we will deal with may be divided into two classes: "bottom-up" and "top-down." The bottom-up studies represent attempts to determine the cost of one or more of the components of local telephone plant, as defined in Section 2 above. In general, this is done by analyzing the components of the telephone network, and applying standard cost factors to the different components. This approach can use existing facilities, or new and hypothetical service areas.

The top-down studies attempt to use aggregate cost and usage data to determine costs or cost functions without performing a detailed analysis. Many of these studies use statistical techniques. Although there is an extensive and growing literature on the econometrics of cost functions, this

literature has to date scarcely been applied to local service.[7] The
studies we deal with are essentially attempts to relate costs to output
measures such as the number of subscribers and the traffic they generate.
Also included in the top-down category are studies which use data generated
by engineering cost models and fit a statistical function to them.

3.1   Bottom-Up Cost Studies: Random Samples of Loop Plant

We first consider the three studies of the loop plant on which Table 2
was based. These studies were, in one sense, carefully designed and carried
out. They begin with the Bell System's study (Hinderliter, 1963), and
continuing with REA in 1964 (Lally and Hitt, 1966) and GTE in 1968 (Davis
and Lally, 1971). In each study a stratified random sample of loops was
drawn, and each loop examined in detail. The applicable standard costs
(e.g. REA's for the Lally and Hitt study) were estimated for each component
of the loop, and assumptions were made to allow for the partial fill of some
cables containing sample loops. Table 4 summarizes the cost results for GTE
and REA (AT&T's published report does not contain cost data). Table 7,
below, shows some cost functions estimated using the sample data.

Unfortunately, these studies are flawed--they do not produce an econom-
ically meaningful estimate of the incremental cost of a loop. Instead, each
study produces, in effect, a detailed estimate of the average reproduction

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[7] A number of recent studies such as Mantell (1975), Vinod (1972), Denny,
Fuss, and Everson (1980), and Nadiri and Schankerman (1950), and
Christensen, Cummings, and Schoech (1980), have applied this methodology to
data for long-haul telephony.

Table 4

SOME ENGINEERING ESTIMATES OF SUBSCRIBER COSTS

Source	Date	Scope	Cost ($)	Comments
REA	1964	Median cost per loop	335	Based on random sample of loops
GTE	1968	Average cost per loop	657	Based on random sample of loops
ITU	1968	Cost for "local network and telephones," to add a main line, excluding "switching equipment"	490	Average of 10 countries in 1968
ITU	1968	Cost of local network and subscriber equipment per main line	300-500	ITU range of "realistic" costs
Hall	1975	"Average" loop	239	Includes $39 for inside wiring station apparatus
Hall	1975	Loop at 23 kft	739	Includes $39 for inside wiring station apparatus
BNR	1980	First cost per channel, new applications, 24 channels and 10 kft	200	Excludes switching, inside wiring or station apparatus
BNR	1980	First cost per channel, new applications, 24 channels and 20 kft	430	Excludes switching, inside wiring or station apparatus

cost of the plant in place at the time when the study was made. However,
each report notes that much of the plant in place did not conform to the
technical standards in existence at the time of the study. That is, had the
sample of loops been built at the time of the study different, and presum-
ably more stringent and costly, standards would have been applied. Conse-
quently, the cost estimates shown in Table 4, and also the cost functions
shown below in Table 7, underestimate the incremental cost of a loop.

3.2 Engineering Cost Estimates for New Loops

In contrast, a report by BNR, Inc. (1978), commissioned by REA, con-
siders future costs. BNR's approach was to estimate the cost of designing
narrow band paired-cable systems under a variety of assumptions about (1)
loop lengths, (2) the number of channels provided simultaneously, and (3)
whether these channels were provided as a new application or to existing
pairs. Table 5 summarizes a much larger body of data contained in the BNR
report. For comparison with other studies, Table 4 also gives BNR's results
for 24-pair cable (the most common choice, according to the BNR report), at
distances of 10 kilofeet and 20 kilofeet. (Ten kilofeet is approximately
the average distance for GTE and Bell System loops, and 20 kilofeet is
slightly more than the average distance for REA loops.) As can be seen in
Table 4, BNR's estimates of the first cost per channel for a new application
at 20 kilofeet ($430) exceeds REA's estimate of median cost per loop
($335). How much of this difference is due to inflation and how much
to the above-mentioned bias in the REA sample's survey methodology is
impossible to determine.

Table 5

COST PER VOICE CHANNEL USING A PAIRED EXCHANGE CABLE

Number of Channels	First Cost at a Distance of 10 kft		First Cost at a Distance of 20 kft	
	New Application	Existing Pairs	New Application	Existing Pairs
12	300	300	600	650
24	200	200	450	430
48	150	150	400	360
96	130	130	300	300

Source: BNR (1978)

3.3 Bottom-Up Cost Studies: The ITU Survey

Another source of information on incremental costs is a survey sent by the International Telecommunications Union (ITU) to member Administrations (i.e. member nations) in 1968. Ten Administrations responded to the survey, which asked for information on their telephone systems including the cost of adding a long-distance circuit and the cost of adding a main line "in the last three-five years." This cost per added main line is further broken down into three categories:

1. Local network and telephones

2. Switching equipment

3. Long distance equipment

The category local network and telephones corresponds to the first two categories in our taxonomy. The average cost for the 10 countries is reported as $490 per main telephone (shown in Table 4). For the first two ITU categories the combined average is $830. However, the ITU estimate includes the switching equipment costs associated with long distance service.

The ITU published an analysis of their data which addresses the question of whether there are economies of scale in the cost of providing local service.[8] In particular, they examined the cost of local network and subscriber's equipment as a function of the main line density. They suggest a "realistic" cost range of $300-$500 per main line, for densities between 0.5 and 45 main lines per square kilometer (see Table 4). However, inspection of a plot of density against cost per main station suggests that there may be slight economies of scale at the lower end of this density range, since the ITU's "realistic" range excludes two outliers (out of ten sample points), both with higher costs, located at 0.3 and 5.5 main lines per square kilometer. (The Bell System "rural" exchange depicted in Table 1 above has a main line density per square kilometer of about two.)

Also relevant from the ITU study are the data summarized in Table 6, showing ten country averages of the share of costs per added main line, averaged across 10 countries. As can be seen the local area network and subscriber equipment represents about 45 percent of total costs. This

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[8] Alleman (1977b), also discusses this question. Briefly, older studies showed diseconomies of scale, but newer ones show constant or increasing returns to scale.

percentage is relatively constant over the 10 countries; the lowest reported

share is 37.4 percent while the highest is 56 percent.

Table 6

AVERAGE SHARES OF COST FOR AN ADDED MAIN LINE

	Cost Share per Added Main Line
Local area network and subscribers' equipment	45.4
Switching network, both local and long distance	31.5
Long-distance network	23.1
Total	100.0

Source: ITU (1968).

3.4 Top-Down Cost Studies

Two studies by economists develop cost functions using a top-down approach: Littlechild (1970) and Alleman (1977b). The first of these is a study of peak load pricing of telephone calls, and the second is concerned with the usage sensitive pricing of local service. Both studies therefore focus more on the demand side than on the cost side, and the cost functions are provided as incidental to the main investigation.

Littlechild's study includes the cost function for local central offices shown in Table 7. As can be seen it involves a substantial fixed cost, plus a small cost per subscriber for switching equipment and an additional cost associated with traffic generated by a subscriber. This function appears to be based on data supplied by Illinois Bell during

Table 7

Cost Functions for Components of Local Telephone Plant

Source	Scope	Functional Form	Comments
Littlechild [1970,p.208] [1979,p.65]	Illinois Bell Central Office	Installed cost = $1,007,000 + $23 \cdot Q_1 + 27 \cdot Q_2$	Assumes 1.3 attempts/completed call, 5 min. call duration, and incoming traffic = originating traffic. C.O. capacity stated as 72,000 ccs.
Alleman [1977]	Summarizes SAI Model of Local Distribution Costs (excluding terminal equip.)	Exchange Area Cost = $15,680,000 + 181\,Q_1 + 4.04E$	Line was fitted for 49,000 to 980,000 subscribers in 49 sq. mi. area, 0.0833 busy hour Erlangs/subscriber, 50% intra-office calling.
Lally and Hitt [1966]	REA borrowers' subscriber loops	$\text{Loop Cost} = \begin{cases} 400\ \$/\text{mi for loops under 12 miles} \\ 450\ \$/\text{mi for loops over 12 miles} \end{cases}$	Represents costs of REA borrowers' in-place loops at 1964 standard costs
Davis and Lally [1971]	GTE subscriber loops	Loop cost per main station = 21.50 $/kft	Represents costs of GTE's in-place loops at 1968 standard costs.
Davis and Lally [1971]	GTE Subscriber Loops	Loop Cost = $58.08 + 15{,}841L + 1.1758L^2 + 0.04215L^3 - 0.000529L^4$	

Q_1 = number of subscriber lines
Q_2 = busy hour usage, ccs
E = traffic in erlangs
L = length of loop, kft

Littlechild's study. The $23 per subscriber figure is consistent with Hall (1975) who gives a cost for central office switching of $25-$40 per subscriber.

Littlechild's function can be used to estimate a full cost per subscriber if we assume that all subscribers generate equal amounts of traffic. Since Littlechild's central office had about 25,000 lines, it is appropriate to use the value of 3.1 CCS per main station given in Table 1. The implied incremental cost is $107.00 on this basis (3.1 × $27 + $23). For comparison, the ITU study cited above gives a ten-country average cost for both local and long-distance switching equipment of $340, three times Littlechild's value.

Alleman's 1977 study is a pseudo-data regression[9] of data from a series of local exchanges designed by a model developed by SAI, Inc. (1976). This model included all costs in the first three items in our typology except the cost of the subscriber's station equipment. Alleman reports making a series of runs at comparatively high subscriber densities (over 2500 subscribers per square mile) and then fitting the linear function shown in Table 7 to the cost estimates produced by the model. Once again this function shows a substantial estimated "fixed" cost which is presumably associated with the land, buildings, and other facilities needed to support subscribers. Also shown are costs per subscriber and per Erlang. Using Alleman's value for average traffic per subscriber (0.417 Erlangs), and for a telephone instrument (equivalent to $59) gives an incremental cost per subscriber of $242 (181 + 59 + 4.04 × .417).

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[9] This "pseudo-data regression" technique has been popular in energy modeling for the last several years. See, e.g., Griffen (1977).

4. AN ECONOMETRIC MODEL OF LOCAL TELEPHONE COSTS

This section presents a purely econometric model of local rural tele-
phone costs. We specify a simple cost model of rural telephone service, and
we estimate it us'ng data from REA borrowers. The data used are presented
in Appendix A. Briefly, they represent the annual aggregate of the account-
ing data on the books of REA borrowers. The next section presents the
model, and subsequent sections discuss the econometric results and present a
sensitivity analysis of them.

4.1 Model Description

In this section we will use capital letters to denote industry aggre-
gate values and lower case letters to denote the values for a representative
firm, to which our cost function will refer. Let:

k_{it} = Gross Telephone Plant-in-Service, at the start of
period t , for borrower i .

g_{it} = Gross investment in telephone plant during period t for
borrower i.

q_{it} = Number of subscribers added during period t, for
borrower i .

z_{it} = Other variables affecting cost

c_{it} = $\phi_t(q_{it}, z_{it})$ = First cost of servicing q_{it}
new subscribers, equal to net investment.

The function ϕ is the first cost of providing subscribers with service.
Unfortunately, c_{it} is not directly observed unless economic depreciation

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is zero.[10] To allow us to proceed we assume that economic depreciation is geometrically determined. This gives us the following two difference equations involving c_{it}, k_{it}, and g_{it}:

$$k_{it} - k_{i,t-1} = c_{it} \tag{4.1}$$

$$k_{it} = (1 - \delta)k_{i,t-1} + g_{it} \tag{4.2}$$

Equation 4.1 is simply the definition of c_{it}, and Equation 4.2 is the definition of g_{it}, assuming geometric depreciation, where δ is the depreciation rate. Combining these equations to eliminate k_{it} gives:

$$c_{it} - (1 - \delta)c_{it-1} = g_{it} - g_{it-1} \tag{4.3}$$

To avoid a solution for c_{it} which involves an infinite series, we use the following approximation for small values of δ:[11]

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[10] Economic depreciation is the rate at which the value of the services provided by a capital asset is exhausted. It need not bear any relationship to accounting depreciation, especially for electrical equipment which, if properly maintained, has an essentially infinite life.

[11] The most direct derivation of this approximation uses the lag operator, which has the property that $Lx_t = x_{t-1}$. From Equation 4.3, the transfer function between c_{it} and g_{it} is:

$$\frac{1 - L}{1 - (1-\delta)L} = \frac{1}{1 + \delta L/(1-L)}$$

$$= 1 - \frac{\delta L}{1 - L} + 0(\delta^2)$$

where the last line follows after expanding the geometric series. Hence:

$$c_{it} = g_{it} - (\delta L/(1-L))g_{it} + 0(\delta^2)$$

$$g_{it} = \phi_t(q_{it}, z_{it}) + \delta\left(\sum_{n=-\infty}^{t-1} g_{in}\right) + 0(\delta^2) \qquad (4.4)$$

Ignoring terms of second-order and higher in δ Equation 4.4 says that the gross investment in plant equals the cost of new plant plus δ times the book value of the plant. This approximation will be exact when $\delta = 0$, but when $\delta \neq 0$ we can estimate δ, thereby validating the approximation.

Equation 4.4 applies to an individual firm. The data we have used, however, is aggregated. Let:

N_t = The number of REA borrowers reporting in year t.

$$K_t = \frac{1}{N_t} \sum_{i=1}^{N_t} k_{it}$$

$$Q_t = \frac{1}{N_t} \sum_{i=1}^{N_t} q_{it}$$

$$Z_t = \frac{1}{N_t} \sum_{i=1}^{N_t} z_{it}$$

$$G_t = K_t - K_{t-1}$$

$$S_t = \sum_{n=1}^{t} G_n$$

Then we have the following equation for the "representative" borrower:

$$G_t = \phi_t(Q_t, Z_t) + \delta S_{t-1} + \epsilon_t \qquad (4.4')$$

where the error term ε_t includes any error associated with ϕ, the approximation error $O(\delta^2)$, and another error due to the fact that S_t is computed only from time $t = 1$ instead of time $t = -\infty$.

It remains to select a functional form for ϕ and to choose the z_{it} variables. We ultimately selected the simplest functional form possible, namely one linear in q_{it} and t only, and with $\delta = 0$. This choice is presented first, but the sensitivity analyses presented later, which use other functional forms and variables, support this selection. It is probably true that a more complex functional form would be appropriate, as might the use of additional variables. Those variables that were available did not produce sensible results when added to the specification, probably because we had about 20 years of data to work with--a very small data set.

4.2 Basic Regression Results

Table 8[12] shows a summary of the four equations that were estimated at first, assuming $\delta = 0$. Two of these involve the logarithms of the variables, two involve the absolute values. The specific variables used are defined as follows:

AGRINV = First difference of gross telephone plant-in-service for all REA borrowers, deflated by the equipment component for GNP deflator, and divided by the number of borrowers reporting in the year t .

APHONES = First difference of the total number of subscribers reported for all REA borrowers divided by the number of reporting borrowers.

YR = The year of the report, 1900 = 0.

All logarithms are natural logarithms.

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[12] In the tables reporting regression results, the figures in parenthesis are the standard errors of the associated coefficients.

Table 8

SUMMARY OF REGRESSION RESULTS
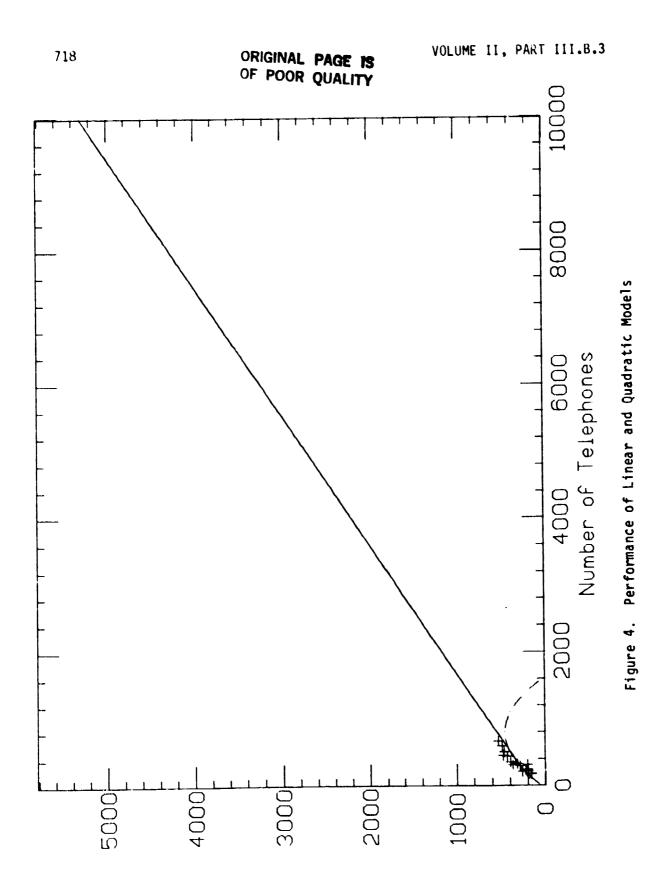
$\ln(AGRINV)$ = 0.0125 + 0.575 $\ln(APHONES)$ + 0.0337 YR R^2 = 0.970
          (0.2395) (0.0596)   (0.00390)   n = 21

$\ln(AGRINV)$ = -8.75 + 3.60 $\ln(APHONES)$ - 0.264($\log (APHONES)^2$ R^2 = 0.980
          (3.05) (1.05)   (0.0916)   n = 21
                                                         SE = 0.0640
          + 0.0354 YR   DW = 1.66
            (0.00345)

$AGRINV$ = -550.1 + 0.517(APHONES) + 9.85 YR R^2 = 0.971
          (70.86) (0.0524)   (1.18)   n = 21
                                                    SE = 22.78
                                                    DW = 1.14

$AGRINV$ = -616.0 + 1.047(APHONES) - $6.648 \times 10^{-4}(APHONES)^2$ R^2 = 0.981
          (61.5)   (.173)   (2.105×10^{-4})   n = 21
                                                              SE = 18.61
          + 9.53 YR   DW = 1.70
            (0.972)

On inspection of Table 8, one might conclude that adding a quadratic term to either the absolute or logarithmic specification significantly improves the fit. However, Figures 4 and 5 show the implied cost functions, plotting costs as a function of the number of telephones for larger numbers of subscribers than appear in the sample.[13] As can be seen, both quadratic forms give absurd results outside the sample region. (The average number of new telephones per borrower per year is about 300). Both quadratic equations indicate a maximum in total cost and, eventually, additional telephones come for zero or negative costs. These absurd results lead us to reject both the higher order models.

The choice between the linear and the log-linear models on the basis of their total cost predictions is at first less clear. In view of the fact that least squares used a different metric in the two cases, one function or the other fits the available data slightly better depending upon how it is plotted. We have selected the linear specification over the log-linear specification because (1) it is the same form as used by others such as Littlechild and Alleman, and (2) it implies a positive, constant marginal cost per subscriber. As seen in Table 8, a point estimate of this cost is $517 per subscriber. In contrast, the log-linear specification implies both average and marginal costs fall to zero. This implication is shown in Figure 6 which plots the two average cost functions, as well as the average costs implied by the data.

We now inquire whether the economic depreciation rate, δ, omitted from the equations shown in Table 8, is important. This question is

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[13] In plotting Figures 4, 5 and 6 the time variable is at its average value. Individual data points are not adjusted for time.

Figure 4. Performance of Linear and Quadratic Models

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Figure 5. Log-Linear and Log-Quadratic Models

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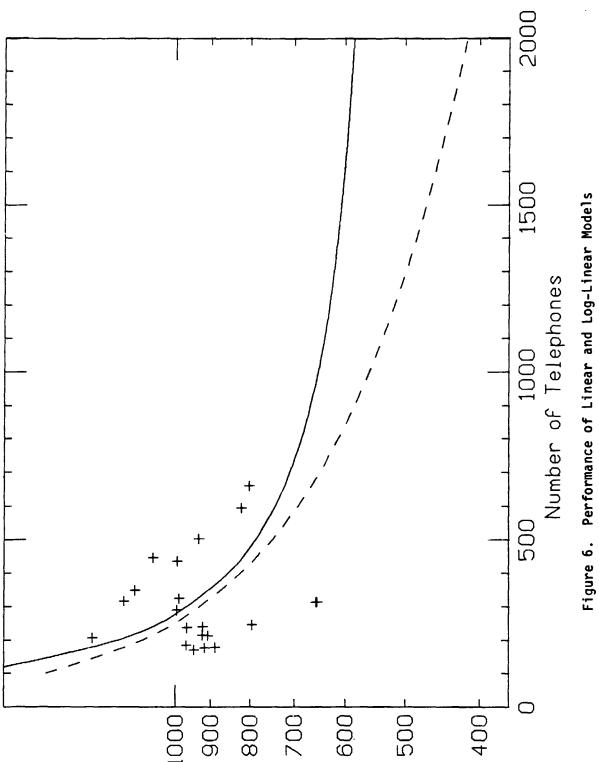
Figure 6. Performance of Linear and Log-Linear Models

addressed in Table 9. The linear model with $\delta = 0$ is shown in the first

column as Equation 4.5. Equation 4.6 adds the depreciation term using the

approximation developed in Equation 4.4. As can be seen, the estimated

value of δ is approximately 0.57% $\pm$ 2.0%. Thus, the value of δ is not

significantly different from zero, and in any case is estimated to be quite

small. The incremental cost per borrower shown in Equation 4.6 is essen-

tially the same as in Equation 4.5, given the estimated standard errors for

both functions. Equation 4.6 implies that Equation 4.5 is in fact the more

parsimonious specification, and we take it to be the base case from now on.

The other two equations in Table 9, Equation 4.7 and Equation 4.8, test

the hypothesis that the cost is given by a distributed lag over several

years. This test is performed by adding a lagged value for APHONES. In

Equation 4.7, this value is added with the time trend included, in 4.8 it is

added with the time trend deleted. In both cases, the coefficient is not

significantly different from zero and is quite small in comparison to the

coefficient on APHONES.

4.3 Sensitivity Analyses

This is probably the place to address the Durbin-Watson statistics,

tabulated in Tables 8 and 9.[14] The Durbin-Watson is suspiciously low in

all four equations. However, for 20 observations and 2 regressors (the case

in Equation 4.5) the upper and lower 5% critical values of the Durbin-Watson

_____

[14] Strictly speaking the Durbin-Watson should not be tabulated for Eqs. 4.6
through 4.8 because the lagged value of real plant-in-service is, in effect,
a lagged endodgenous variable. However, when the coefficient of the lag
variable is small, the "correct" test, involving Durbin's "h" statistic, is
approximately the same as the Durbin-Watson.

Table 9

RESULTS OF DISTRIBUTED LAG TESTS
(Dependent Variable is Gross Real
Investment/Borrower)

Coefficient	Equation			
	(4.5)	(4.6)	(4.7)	(4.8)
Intercept	-550.1	-498.0	-639.3	67.6
	(70.86)	(300.2)	(459.8)	(16.0)
New Phones/Borrower (Q_t)	0.517	0.489	0.481	0.474
	(0.0739)	(0.0783)	(0.0814)	(0.0814)
Lagged New Phones/Borrower (Q_{t-1})			0.0465	-0.0802
			(0.112)	(0.0796)
Real Plant-in-Service/Borrower (S_{t-1})		0.00566	-0.00481	0.0442
		(0.0196)	(0.0325)	(0.00710)
Year (YR)	9.85	9.03	11.25	
	(1.18)	(4.84)	(7.31)	
R^2	0.971	0.971	0.971	0.966
n	21	20	20	20
DW	1.14	1.09	1.16	0.911

statistic are 1.10 and 1.54.[15] A test for first order autocorrelation is

thus inconclusive. An inspection of the residuals did not reveal any

obvious problems, however the possibility that an omitted variable was the

cause of the low Durbin-Watson could not be ignored.

On the other hand, in view of the small number of data points, the

number of additional specifications which could be explored is quite

limited. Table 10 shows two attempts to add plausible additional variables

to the cost function. In Equation 4.9 the number of added central offices

per REA borrower was included as an explanatory variable. Its coefficient

was not significant, and did not much perturb the other coefficients. In

Equation 4.10 examined the possibility that the marginal cost per subscriber

depended on the average distance from subscriber to central office. The

coefficient was made to vary linearily with the number of added miles per

borrower per new telephone. This coefficient also was not significant,

although it was slightly positive as expected from the engineering studies.

In neither case was there any improvement in the explanatory power of the

equation and the Durbin-Watson was essentially unchanged. We conclude that

if the basic relationship (Equation 4.5) was misspecified the problem is not

easily repaired

The next item to be examined involves the time trend, which has been

significant in the regressions so far. The coefficient indicates that the

constant term is increasing by about \$9000 to \$10,000 annually. Some of the

---

[15] The bounds for three regressors are 1.00, 1.68.

Table 10

ALTERNATIVE SPECIFICATION INVOLVING CENTRAL OFFICES AND LENGTH OF HAUL
(Dependent Variable is Gross Real Investment per Borrower)

	Equation		
	(4.5 repeated)	(4.9)	(4.10)
Intercept	-550.1 (70.86)	-739.6 (224.5)	-604.8 (124.4)
New Phones/Borrower	0.517 (0.0524)	0.437 (0.102)	0.488 (0.0765)
Added Central Offices		96.98 (139.3)	
Average Length of Haul × (Phones/Borrower)			0.0101 (0.534)
Years	9.85 (1.18)	12.71 (3.38)	10.75 (1.98)
R^2	0.971	0.971	0.970
n	21	19	19
DW	1.14	1.12	1.07

runs in Table 11 were made to explore alternative time trend specifications. Equation 4.11 allows the time trend to affect the marginal costs per subscriber, but not the constant term, while Equation 4.12 allows both to be affected. Finally, Equation 4.13 allows marginal costs to depend both on the number of subscribers and time. At first all three specifications appear plausible, and Equation 4.13 improves the Durbin-Watson. Once again, however, these equations must be rejected because of their unreasonable implications. For example, the slope estimated in Equation 4.11 implies that the cost of service to an additional subscriber was zero in 1956, and negative in previous years. Similarly, Equation 4.12 contains the optimistic implication that marginal cost will fall to zero in the year 2003. Equation 4.13 has the same difficulty as the earlier quadratic equation, predicting negative marginal costs for large numbers of subscribers.

To summarize, nothing in the equations constituting the sensitivity analysis justifies more than a simple linear equation with $\delta = 0$. That regression, Equation 4.5, indicates that quasi-fixed charges are growing with time but that the marginal cost of adding a subscriber has been in constant with time. The full function for the year 1972, including the standard errors for that year, is:

AGRINV = 159.1 + 0.517 APHONES
         (19.96) (0.052)

Table 11

ALTERNATIVE LINEAR-QUADRATIC SPECIFICATIONS
Dependent Variable is Gross Real Investment per Borrower

	(4.5 repeated)	(4.11)	(4.12)	(4.13)
Intercept	-550.1 (70.86)	132.6 (27.75)	-931.2 (206.3)	-21.47 (30.58)
Phones/Borrower	0.517 (0.0524)	-1.323 (0.447)	1.824 (0.672)	-0.623 (0.288)
(Phones/Borrower)^2				1.326×10^{-3} (2.23×10^{-4})
Year (YR)	9.85 (1.18)		15.14 (2.92)	
(Phones /borrower)(Year)		0.0258 (0.00533)	-0.0177 (0.00908)	0.0299 (0.00320)
R^2	0.971	0.938	0.976	0.980
n	21	21	21	21
DW	1.14	0.870	1.29	2.03

5   SUMMARY

The econometric equation suggests that the incremental cost per sub-
scriber for a typical REA borrower is approximately $520 in 1972 terms.
Average costs in 1972, at the sample mean of 315.1 new subscribers per
borrower, are $1,023 ± $75 per subscriber.

How does this estimate agree with other studies? The engineering cost
estimates examined in Section 3 can provide some additional information.
REA loop costs are approximately $335, in 1964 dollars (Table 4). Applying
our deflator to convert to 1972 dollars gives $418 for the loop cost; apply-
ing the ITU cost share from Table 6 (45.4% divided by 45.4% + 31.5%) gives
an estimated cost of $5'·ʳ dollars for the incremental costs of the local
area network, subscriber equipment, and switching. Alternatively, adding
the $107 per subscriber derived for Littlechild's equation for local switch-
ing gives $525. Notice that all these figures disregard the additional
costs associated with long distance, which are unlikely to be incurred by
the local rural company. Including the long distance cost share give $921
per subscriber as an estimate of overall incremental costs to all companies.

In addition to these costs we recall the estimate by Alleman (for an
urban/suburban exchange area) that was equivalent to $243 for an incremental
subscriber, and the estimate from Hall (1975) for a local area network
(including a 23 kft loop), subscriber equipment, and local switching of
$764-$779. Finally BNR gives a per channel cost of $430 for a 20 kft
circuit. All these estimates are summarized in Table 12.

Several things are apparent. First, when our attention is restricted
to subscriber equipment, loop and local exchange plant, the bottom-up

Table 12

POINT ESTIMATES OF THE INCREMENTAL
COST PER SUBSCRIBER

Source	Scope[1]	Value
Alleman (1977b)	1-3	$ 242
BNR (1980), 20 kft	2	430
ITU 1968: Cost of local network and subscriber equipment	1-2	490
Equation 4.5	1-3	517$\pm$52
REA loop plant survey + Littlechild switching cost equation	1-3	525
REA 1964 Survey + ITU, excluding long distance investment, 1972 dollars	1-3[2]	543
Hall (1975)	1-3	764-779
ITU 1968 Survey excluding long distance investment (1968)	1-3[2]	830
REA 1964 Survey + ITU , including long distance investment, 1972 dollars	1-4	921
Average Annual Change in Telephone Plant-in-Service per Added Subscriber, 1958-79, 1972 dollars	1-3 ?	940

Notes:
1   Numbers refer to the four-part taxonomy introduced in Section 2.
2   Includes costs of added long distance switching associated with an added subscriber.

5   SUMMARY

The econometric equation suggests that the incremental cost per sub-
scriber for a typical REA borrower is approximately $520 in 1972 terms.
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(including a 23 kft loop), subscriber equipment, and local switching of
$764-$779. Finally BNR gives a per channel cost of $430 for a 20 kft
circuit. All these estimates are summarized in Table 12.

Several things are apparent. First, when our attention is restricted
to subscriber equipment, loop and local exchange plant, the bottom-up

estimates do not differ greatly from the top down estimnates. Although the

range is from about $240 to $775, most of the estimates cluster around $500.

The second point is that our econometric estimates, along with the

studies of Littlechild and Alleman, suggest that there are substantial

investment costs that are not associated with additional subscribers. In

1972, our econometric study estimates these costs to be $159 thousand

($\pm$ $20 thousand) per REA borrower, and implies that they were increasing at

$9,900 $\pm$ $1,200 annually after adjusting for inflation. The other two

studies show fixed costs per exchange to be $1 million and $15.68 million

respectively. (However, the exchanges involved in these cases are much

larger than the typical rural exchange, so these magnitudes cannot be used

as standards for comparison.)

In fact, it is not certain that the intercept term found in the regres-

sions necessarily represents fixed costs, i.e., the costs of identifiable

equipment whose provision does not depend on the number of subscribers

served. Looking at Table 10, we see that when the number of central offices

is included as an explanatory variable the intercept $175.5 thousand in

1972. But the central office equipment, and the associated land and build-

ings, are likely to be the major source of costs. This variable should

enter positively into the regression, while reducing the size of the inter-

cept. It did not do so.

Another possible explanation for the intercept is a change in the

quality of service. In fact, the period from 1957 to 1979 saw a major

improvement in service as single party service replaced multi-party. How-

ever, this change does not seem to be the reason for the intercept, because

inspection of the subscriber series published by REA indicates that virtually all additional subscribers received one-party service. Thus, Equation (4.5) really pertains to a new one-party subscriber, and the intercept should not be due to some change in the mix of one- and multi-party subscribers.

One possible explanation for the positive constant term, of course, is that the independent variable (APHONES) is measured with error. In general, this will result in inconsistent estimates of the regression coefficients when least squares is used. Indeed, in the simple regression model, it can be shown that if the errors in measuring the dependent and independent variables are independent the slope will be underestimated asymptotically (Malinvaud, 1970). The intercept will be overestimated as a consequence. Something like this may be happening in Equation 4.5, but we cannot be certain unless different data (for example, on the actions of individual borrowers) are used.

APPENDIX A

The data used in this study is taken from the REA's <u>Annual Statistical</u>

<u>Reports</u> for the years 1963-1979 and covers the period 1956-1979. In addi-

tion, the deflator used was taken from the <u>Economic Report of the President</u>.

- Gross telephone plant in service,

- Accumulated depreciation on telephone plant

- Total subscribers served,

- Miles of lines,

- Central offices, and

- Number of borrowers (used to weight the data).

Table A.1 shows the raw data, Table A.2 shows the data used in the regres-

sions on plant, derived from Table A.1.

The data on the change in telephone plant have not been adjusted for

retirements because REA does not report retirements separately. These seem

likely to be small, however, so that the change in investment reported in

Table A.2 is unlikely to be much affected.

Table A.1
Data from REA Annual Statistical Reports

Year	Telephone Plant-in Service (thousands of dollars)	Depreciation Reserve (thousands of dollars)	Number of Telephones	Number of Central Offices	Number of Miles of Line	Number of Borrowers Reporting	Equipment Component of GNP Deflator
1956	·	·	·	·	·	·	71.10
1957	·	·	·	·	·	·	75.50
1958	338843	41721	858803	2575	·	588	76.60
1959	443487	58253	1062574	2956	·	649	78.30
1960	556548	78835	1280270	3275	334153	695	79.40
1961	670727	101589	1461298	3530	355273	737	79.30
1962	787862	128833	1623800	3735	383701	761	79.40
1963	888981	157518	1762244	3897	414271	784	79.70
1964	993202	189740	1899904	4031	431475	804	80.10
1965	1097608	224792	2045956	4165	460141	816	80.60
1966	1216175	265227	2195346	4259	482005	814	82.10
1967	1351308	308977	2369153	4399	499179	811	84.30
1968	1513272	354789	2561495	4517	533559	811	87.20
1969	1673357	398602	2754689	4612	554190	806	89.90
1970	1890659	452664	2988849	4715	547320	809	93.20
1971	2101367	500321	3157109	4744	568051	816	97.20
1972	2365282	566231	3423892	4822	583922	822	100.00
1973	2699395	647708	3713976	4862	603747	831	101.80
1974	3102119	735891	4084393	4942	627483	848	109.30
1975	3501997	824914	4355445	5017	652884	858	126.20
1976	4053082	955333	4796426	5217	683648	876	133.90
1977	4721632	1143341	5388071	5327	726271	895	140.90
1978	5383643	1327819	5925460	5434	748361	902	150.10
1979	6084294	1518722	6335312	5499	771951	919	159.70

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Table A.2

Data Used in Regressions

Year	Change in Telephone Plant-in-Service per Borrower, Thousands of 1972 Dollars (AGRINV)	Change in Telephones per Borrower (APHONES)	Change in Miles of Lines of Borrower (AMILES)	Change in Central Offices per Borrower (ACOES)
1956	.	.	.	.
1957	.	.	.	.
1958	.	.	.	.
1959	205.924	313.977	.	0.17545
1960	204.884	313.232	.	0.15753
1961	195.364	245.628	28.657	0.07746
1962	193.857	213.537	37.356	0.11833
1963	161.830	176.587	38.992	0.06265
1964	161.833	171.219	21.398	0.04302
1965	158.745	178.985	35.130	0.09049
1966	177.417	183.526	26.860	0.12802
1967	197.657	214.312	21.176	0.19198
1968	229.024	237.166	42.392	0.14550
1969	220.931	239.695	25.597	0.15242
1970	288.204	289.444	-8.492	0.10610
1971	265.659	206.201	25.406	-0.01446
1972	321.064	324.554	19.308	0.05245
1973	394.952	349.078	23.857	-0.01540
1974	434.502	436.813	27.991	-0.02295
1975	369.301	315.911	29.605	0.01949
1976	469.823	503.403	35.119	0.10816
1977	530.151	661.056	47.623	-0.00352
1978	488.965	595.775	24.490	0.07243
1979	477.399	445.976	25.669	-0.04071

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A CHANGING TELECOMMUNICATIONS REGULATORY ENVIRONMENT:
SOME IMPLICATIONS FOR NASA

Dean Olmstead and Alan Pearce*
March 1983

Abstract

This report reviews recent legislative, judicial and regulatory
changes in telecommunications, and discusses the reliance of these changes
to NASA. The report reviews the history of legislative attempts to
rewrite the Communications Act of 1934, the settlement of the U.S. Depart-
ment of Justice's Antitrust suit against AT&T, and changes in the FCC's
role as regulator of the telecommunications industry in general and AT&T
in particular.

These changes mean that the regulatory environment in the future will
be characterized by increased competition in the marketplace and in regu-
latory and legislative arenas. A number of changes in rates, services and
technologies are expected to occur. Consequently, the report recommends
that NASA devote increased attention to these changes, specifically by the
creation of a position in the agency charged with monitoring events in
telecommunications.

* Information Age Economics, Bethesda, Maryland

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DRAFT FINAL REPORT

A CHANGING TELECOMMUNICATIONS REGULATORY ENVIRONMENT:

SOME IMPLICATIONS FOR NASA

March 1983

Prepared for:

>   Mr. Harold Kimball, Director
>   Communications and Data Systems Division
>   NASA Headquarters

Prepared by:

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>
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ABSTRACT

This is the final report on the regulatory investigation component of
a long-range telecommunications planning effort initiated by NASA Head-
quarter's Communications and Data Systems Division. Through extensive
interviews with telecommunications policymakers, research on the history
of telecommunications regulatory changes and experiments which allowed
observation of NASA's response to changes, we have developed a set of
recommendations which will enable NASA to improve its effectiveness.
Briefly, accelerating change in the telecommunications environment points
to the need for increased long-range planning by NASA, an improved manage-
ment decision support system and a more active role for NASA in the
development of domestic telecommunications policy. In order to implement
these recommendations effectively, the responsibilities must be assigned
to a single individual, so we recommend the creation of a new position and
we provide an initial description of that position's responsibilities.

CONTENTS

CHAPTER ONE: EXECUTIVE SUMMARY

A. Background

The Office of Space Tracking and Data Systems (OSTDS) is responsible for managing all communications within NASA. Within OSTDS, the Director of the Communications and Data Systems Division has recognized that changes in the telecommunications environment mandate a more concerted and active role for the Division in long-range strategic planning. An overall effort has been initiated in response to this need. This study comprises one element of the overall effort. It investigates: (1) relevant current and pending regulations and legislation pertaining to telecommunications, (2) the implications of such to NASA, and (3) the possibilities for improving NASA's effectiveness and influence within the telecommunications arena.

B. Study Objectives

1. Overall Effort

The basic objective of the overall effort is the same as that of all NASA network management functions: minimizing NASA's telecommunications costs without sacrificing requirements. However, a different perspective sets this effort, and this study, apart from ordinary studies of network operation and planning. The methodology of a typical planning study is to inventory the system, determine areas for improvement and develop a migration strategy for implementating the changes. Instead, the methodology of the overall study is to identify trends in regulations and technology, determine NASA's potential future requirements, and develop conceptual network plans that are not bound by the status quo. The effort is

intended to provide: (1) specific recommendations for improvements in

network management methods, (2) a well defined set of long-range goals,

(3) a long-range conceptual plan for the networks, and (4) an improved

understanding of the importance of participating in telecommunications

regulatory activities.

2. Regulatory Investigation Component

This report is concerned with the regulatory investigation component

of the overall effort. It is intended to provide information on the

direction of pending regulatory/legislative actions in order to: (1)

improve NASA's understanding of possible opportunities ·nd constraints and

(2) help NASA protect current and future interests. Therefore, this study

has two main objectives. The first is to examine both the telecommunica-

tions regulatory environment and NASA's existing mechanisms for dealing

with change in that environment. The second is to provide specific

recommendations for improving NASA's effectiveness on a continuing basis.

C. Study Methodology

This study was performed by one outside consultant and one intern

working for the Director of the Communications and Data Systems Division.

The work was done on a part-time basis over a 9-month period comprising a

total of two man-months of effort. Interviews were held with prominent

policymakers in the telecommunications arena in order to gain a more com-

plete understanding of existing policies and to determine the general

direction of future policy efforts. Research was conducted on: (1) the

history of significant past changes in the environment including previous

legislative initiatives and (2) the role of technology in increasing competition.

Because of the rapidly changing nature of the telecommunications environment, several new policies which potentially affected NASA were proposed during the course of this study. These provided excellent opportunities for observing NASA's influence on policy development and NASA's mechanisms for reacting to such proposed policy changes. Several NASA actions were initiated during the study (see Appendix D), thus allowing first-hand observations to be made on the effectiveness of the process.

D.   Summary and Conclusions

For many years the telecommunications industry could be characterized by stability and extensive regulation. During this time the common carriers provided virtually all telecommunication services, owned the entire complement of equipment and maintained close business ties with the equipment manufacturers. This monopolistic structure was supported by the policymakers because they believed that the stability of a single integrated system provided the most efficient service possible. In the past few decades, the pace of technological change in the telecommunications industry has accelerated. Many of these technological developments have eroded the justification of a monopoly industry structure. The need for some form of change industry structure has been recognized by the Congress, the Department of Justice and the FCC, and all three are actively involved in determining the shape of the industry for the coming years.

Congress began its recent attempts to rewrite major portions of the
1934 Communications Act during 1976. In each succeeding session legisla-
tive initiatives were introduced, but major legislation has failed to
pass. Congress has taken an active interest in the AT&T antitrust
settlement and it appears that Congress will continue its efforts to pass
major legislation.

The Department of Justice settled its long-standing antitrust suit
against AT&T on January 8, 1982. The traditional monopoly structure of
the industry was perceived by the Department of Justice to be no longer
adequate in light of emerging competition in many sectors of the
industry. In order to change AT&T's incentives to cross-subsidize
unregulated activities out of regulated activities, forestalling
competition, it was deemed necessary to separate AT&T's regulated and
nonregulated activites. To do this, the settlement contains a divestiture
plan whereby AT&T will spin-off its 22 local operating companies which
will remain regulated monopolies. AT&T will be allowed to compete in
nonregulated markets after divestiture.

The Federal Communications Commission has been taking steps towards
increasing competition in the telecommunications industry since the latter
part of the 1950's. Although the development of new technologies has
prompted these decisions by the FCC, it appears that the FCC's decisions
have in turn spurred the development of new technologies. It is this
accelerating cycle which creates the dynamic nature of today's
telecommunications industry.

As discussed in Chapter 6, this dynamic environment has several
significant implications for NASA. As competition in the industry

increases and technology advances, NASA's managers will find available
services and equipment more diverse, and the number of offerers will
increase. In order to prevent unnecessary inefficiencies, longer term
planning to guide procurements will become necessary. For similar
reasons, improved and accessible information on services, tariffs, equip-
ment and contractors will become increasingly important to efficient
decision making. A final implication is that NASA's interaction with the
telecommunications environment will become increasingly valuable. This
interaction is necessary not only for influencing the environment, which
is possible and could be very beneficial to NASA, but also for improving
NASA's ability to react to changes and seize new opportunities.

We have developed a set of recommendations (contained in Chapter 7)
which will enable NASA to improve its effectiveness. Briefly, accelerat-
ing change in the telecommunications environment points to the need for
increased long-range planning by NASA, an improved management decision
support system and a more active role for NASA in the development of
domestic telecommunications policy. In order to implement these recom-
mendations effectively, the responsibilities must be assigned to a single
individual, so we recommend the creation of a new position and we provide
an initial description of that position's responsibilities.

CHAPTER TWO: THE TELECOMMUNICATIONS INDUSTRY

A.   The Years of Stability

For many years, until roughly the 1950s, the telecommunications

industry could be characterized by stability and extensive regulation.

The recent changes resulting from a decrease in both of these characteris-

tics can best be examined by looking at (1) the services rendered, (2) the

facilities from which those services were derived, and (3) the relation-

ship between the providers of the services (the common carriers) and the

manufacturers of the equipment.

In terms of services, the carriers held to the "universal service"

concept whereby they provided telephone, telegraph, private line, video,

data and facsimile. This same concept was applied in terms of facilities

as the carriers provided the entire range of equipment including the

customer premises equipment (terminals), the local distribution facil-

ities, the central office exchanges and the long distance trunks. The

local distribution lines and the attached terminal equipment were seen as

indivisible, and the carriers owned all equipment and leased it to users.

Duplicate or alternative long-haul and local distribution facilities were

viewed as wasteful and contrary to the "public interest." Consequently,

many new technologies were defined as complementary rather than competi-

tive and hence within the purview of the existing monopoly (AT&T).

Finally, the service providers and the equipment manufacturers were ver-

tically integrated. That is, the carriers held ownership in their equip-

ment suppliers (e.g., AT&T ownership of Western Electric). Thus, the

possibilities for potentially competitive firms to enter the telecommuni-

cation services or equipment markets were minimal.

Such a noncompetitive industry structure was supported by the policy-makers as being in the public's best interest. Many believed that the stability provided by a single integrated system not subject to competition was necessary in order to maintain an efficient, universal service. The widely popular natural monopoly thesis held that the existing monopolistic structure provided for lower charges than would otherwise have been required. And, given a Government sanctioned monopoly, regulation was of course necessary.

B.   The Effects of Technological Change

Although technological change in the telecommunications industry was apparent throughout the first half of the century, the past few decades have been different owing to an increased pace in the introduction of substitutes generated by new technology. These technological developments have altered precisely those characteristics of the industry which were used to justify a government regulated monopoly. For over two decades, the Federal Communications Commission (FCC) has been moving towards an increasingly competitive industry by recognizing substitute technologies as properly competitive, and allowing firms other than the traditional carriers to market both new and substitute services and equipment. However, the FCC has found that simply allowing competition is not sufficient to attain a competitive industry. The integration or interconnection of new equipment and services with those already existing must be required, and structural changes in the industry must be mandated.
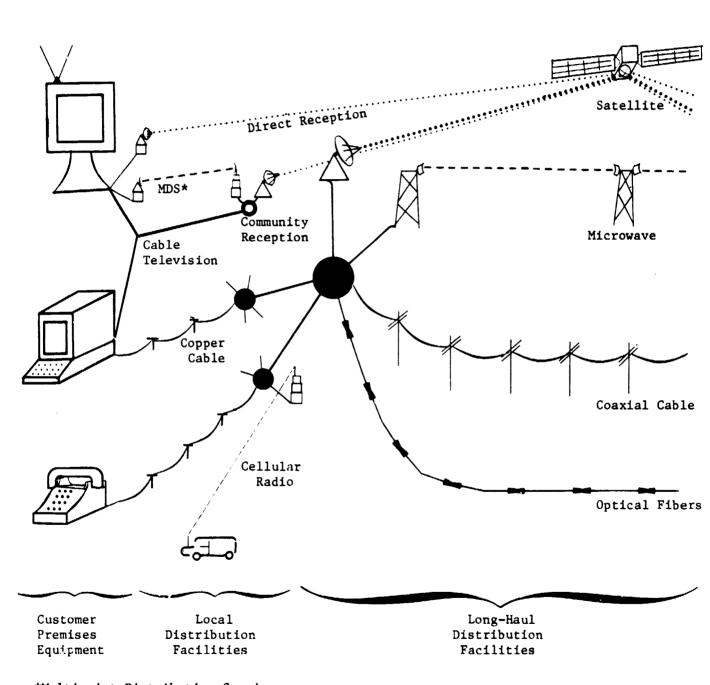
The concept of a sole provider of all services was largely abolished when the FCC approved the entry of specialized common carriers into the

industry, and subsequent decisions have continued to open services to
competition. In 1968, the traditional carriers' control of terminal
equipment was dealt a death blow with the Carterphone decision which
opened the way for any firm to manufacture and market terminal equipment.
This decision required that the carriers allow such equipment to be inter-
connected with the existing network.

Diverse transmission and distribution facilities, which were viewed
as uneconomic and wasteful when provided by copper wire and coaxial cable,
can now be provided efficiently by many new technologies. Figure 1 shows
where these alternative technologies fit into the system. For instance,
multipoint distribution service and cable television provide broadband
alternatives for local distribution, and cellular radio provides a narrow-
band substitute. Satellites provide a substitute for the microwave and
coaxial cable systems used for long distance transmission. And the com-
puter industry is producing hardware both for central office and remote
switches, as well as offering many data processing and software services.
In short, the carriers are losing their once almost absolute control over
services, terminal equipment and switching facilities as well as local
distribution and long-haul transmission facilities (see Appendix A for the
diversity in the industry today).

Once the decision to promote competition in the telecommunications
industry was acted on, the challenges to the traditional industry struc-
ture began snowballing. Today the FCC is undertaking several major inves-
tigations related to competition (see Chapter 5), the Department of
Justice (DOJ) has settled an antitrust suit against AT&T that will reshape
the industry (see Chapter 4) and Congress is attempting to rewrite the
1934 Communications Act (see Chapter 3).

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OF POOR QUALITY

Direct Reception

Satellite

MDS*

Community
Reception

Cable
Television

Microwave

Copper
Cable

Coaxial Cable

Cellular
Radio

Optical Fibers

Customer	Local	Long-Haul
Premises	Distribution	Distribution
Equipment	Facilities	Facilities

*Multipoint Distribution Service

Figure 1

Alternative Transmission and Distribution Technologies

CHAPTER THREE: LEGISLATIVE ACTIVITIES

A. Background

Congress began its recent attempts to rewrite major portions of the
1934 Communications Act (the legislative document governing the telecom-
munications industry) in 1976. In each succeeding session many legisla-
tive initiatives were introduced but only a few narrowly focused bills
passed into law, leaving the act essentially unchanged. Even though the
FCC began promoting limited competitive policies several years earlier,
the first series of legislative initiatives favored retention of a regu-
lated monopoly structure in the telecommunications industry. It was not
until two sessions later, in 1978, that Congress considered major legisla-
tion favoring competition over monopoly in most sectors of the telecom-
munications industry. In each of the next four sessions, through 1982,
Congress tried unsuccessfully to rewrite the Communications Act and move
away from the need for a regulated monopoly. With the entering of the
AT&T/DOJ antitrust settlement, competition is likely to increase even
without the assistance of legislation. However, with this increased
competition, the changes in the role of the FCC and the new structure for
the telecommunications industry, Congress is likely to try once again to
set policy through revision of the 1934 Communications Act.

B. tions in the 94th and 95th Congresses

Attempts to make major revisions in the 1934 Communications Act began
in the 94th Congress with the introduction of H.R.12323 and S.3192 both
known as the "Consumer Communications Reform Act of 1976." This

initiative was introduced in a variety of forms and was reintroduced in the 95th Congress as H.R.8 and S.530. In all forms, it gave a presumption in favor of a monopoly communications network, declaring that an integrated interstate and foreign common carrier service maintains reasonable charges that are "lower than would otherwise be required" and results in an efficient, high quality, universal service. The proposed act favored a single integrated system free from marketplace competition, finding that such competition resulted in inefficiencies and was "contrary to the public interest."

It was not until the second session of the 95th Congress that major legislation favoring competition in the marketplace was submitted. H.R. 13015, the "Communications Act of 1978" attempted to revise all major aspects of the Communications Act of 1934. Among the key common carrier provisions were: (a) the reliance on competition to control rates; (b) the required divestiture of the manufacturing arms of both AT&T (Western Electric) and GT&E, and (c) the lifting of restrictions barring AT&T and other carriers from offering related communications services. None of these initiatives were passed into law.

C.   Actions in the 96th Congress

In the 96th Congress members of both the House and the Senate introduced broad scope legislation (H.R.3333; S.611; S.622). All three bills contained extensive proposals dealing with the deregulation of the common carrier and the broadcast industries. H.R.3333 was later replaced by more limited legislation (H.R.6121) solely addressing common carrier issues, whereas the Senate initiatives were combined and expanded

to include broadcast and cable communications as well as common carrier

issues (S.2827). All actions included deregulation of some markets and

services while retaining regulation over basic telephone services and

"dominant" carriers (e.g., AT&T). The Senate legislation differed from

that of the House in its expanded list of "dominant" carriers and its

retention of the FCC's power to make structural changes in AT&T. But, as

before, several factors prevented the passage of legislation.

D. Actions in the 97th Congress

   Unlike most actions taken by previous Congresses to amend the Com-

munications Act of 1934 through omnibus initiatives, the members of the

97th Congress have taken a different approach to communications reform

by introducing a series of separate measures dealing with more specific

aspects. Although legislation affecting most facets of the communications

industry has been introduced and limited broadcasting and international

carrier measures were enacted, the most far-reaching communications

measures to be introduced in the 97th Congress are S.898, the "Telecom-

munications Competition and Deregulation Act of 1981," and H.R. 5158, the

"Telecommunications Act of 1982." Both bills sought to restructure major

segments of the telecommunications industry as well as AT&T.

   Once again the attempts at major revision did not result in new law.

This time the lack of success was in a large part due to the AT&T settle-

ment of January 1982. The settlement led to a $2 million AT&T lobbying

campaign against H.R.5158. This resistance was aided by opposition to

specific provisions expressed by other groups. The far-reaching impact of

such legislative reform, and the lack of a consensus among communication
specialists regarding the best legislative approach, added to the contro-
versy.

There is a consensus, however, that the incorporation of competition
into the telecommunications industry as well as the elimination of boun-
daries between information and communications due to technological
advances have necessitated the revision of the 1934 Communications Act.
It is the manner in which this should be accomplished which continues to
be a subject of debate. The complexity of the issues, as well as the
simultaneous actions by the courts (and DOJ), the FCC, and the Congress
have created the current environment of uncertainty.

E.   Summary

Even though the Congress has failed to pass broad scope legislation,
this does not mean that it lacks any influence in the policymaking
process. Just the reverse is true. Congress often signals its policy
guidelines to regulatory agencies such as the FCC through proposed legis-
lation. Consequently, NASA should never underestimate the effect that
proposed legislation may have on the Executive Branch—or even the
Judicial Branch for that matter.

A good example of the influence of Congress on the Judicial Branch is
a letter written by Congressman Tim Wirth, D-CO., Chairman of the House
Telecommunications Subcommittee, to Judge Harold Greene, who is presiding
over the AT&T antitrust case, following Wirth's "withdrawal" of H.R.5158
in late July. Wirth—and several of his colleagues—made a number of
suggestions regarding modifications of the antitrust settlement between

AT&T and the Justice Department. Judge Greene, in his proposed modifications announced on August 11, 1982, included several of Wirth's suggestions in his order which have now been included in the final judgement.

The Chairmen of the Senate .d the House Telecommunications Subcommittees have both expressed a "wait and see" attitude towards the AT&T settlement. However, given the changing technology and the consensus that Congress needs to provide telecommunications policy guidance, it is almost certain that future Congresses will continue to grapple with revisions of the 1934 Communications Act.

Congress	Year(s)	Bill Number	Comments
94th	1978	H.R.12323 S.3192	All of these initiatives gave a presumption in favor of maintaining a <u>monopoly</u> controlled industry, finding that competition led to inefficiencies.
95th	1977	H.R.8 S.530	
	1978	H.R.13015	This was the first major submission favoring <u>competition</u> in the industry.
96th	1979	H.R.3333 S.611 S.622	All of these actions included deregulation of some markets and services while retaining regulation over basic telephone service and dominant carriers.
	1980	H.R.6121 S.2827	
97th	1981 1982	S.898 H.R.5158	Both initiatives favored competition but were different from previous actions in that their provisions were much more specific, seeking to restructure major segments of the telecommunications industry as well as AT&T.

Figure 2

Major Attempts to Revise the 1934 Communications Act

C - 4

CHAPTER FOUR: THE SETTLEMENT

A.   Introduction to the Settlement

August 24, 1982, marked the beginning of a new age in the telecom-
munications-information industry. On that date the Justice Department's
historic antitrust suit against AT&T was finally settled when Judge Greene
signed the Modified Final Judgement. The settlement will have a major
impact on industry structure, the degree of competition, the services
offered, and the Federal/State regulatory policy relationship.

The suit, brought in November 1974, when the Federal Communications
Commission was promoting limited competitive policies in the telecommuni-
cations industry, was settled at a time when the Congress, via two bills,
was attempting to prevent AT&T from offering services in parts of the
newly emerging and potentially lucrative information sector, i.e., elec-
tronic publishing and broadband communications. In addition, prior to the
settlement, AT&T would only have been able to enter competitive areas of
the telecommunications-information industry via separate subsidiaries
under close scrutiny by the FCC.

Clearly, the settlement demonstrates that AT&T will go to great
lengths to avoid having its business opportunities limited by the Congress
or the FCC.

B.   Theory of the Settlement

Within the telephone industry, three virtual monopolies have
developed: local exchange service; toll, or "long distance" service; and
equipment manufacturing. The theory of vertical foreclosure is used to

explain AT&T's activity in all three of these markets. Put simply, the
theory holds that AT&T is subject to rate-of-return regulation and rate-
of-return regulation limits profits. Therefore, AT&T has an _incentive_ to
increase profits by shifting them out of the regulated activities into
nonregulated activities. The primary way profits are shifted is by
cross-subsidizing competitive services.

To help alleviate perceived detrimental effects of AT&T's activities
in these three markets, the Department of Justice has supported the prin-
ciple of open entry. But, by itself, open entry is not sufficient to
ensure competition since distorted incentives still exist. It was the
desire to change the incentives that led the Department of Justice to the
divestiture approach with the original intent of achieving total separa-
tion of regulated and nonregulated activities.

The divestiture plan that led to the settlement incorporated compro-
mises to the "ideal" divestiture as envisioned by the Department of
Justice. Judge Greene's subsequent modifications resulted in further
compromises, and further adjustments are sure to arise in the implementa-
tion process. There is little doubt that AT&T's incentives will be
greatly altered, but whether or not the Department of Justice's objectives
will be realized depends on several unresolved issues such as the rela-
tionship between the FCC and the state regulatory agencies, the effective
separateness of separate subsidiaries, and the remaining advantages of
Western Electric.

C.   **Presettlement Structure of AT&T**

AT&T is the dominant player in the domestic telecommunications-
information industry. The company has roughly $140 billion invested in
plant and equipment, employs about one million people, has 2.9 million
shareholders, and is responsible for 8 percent of all plant and equipment
investment in the U.S. Last year, the company grossed about $60 billion
in revenues and made an after tax profit of over $7 billion. This year it
plans to invest about $23 billion in new plant and equipment. In addition
to the 22 Bell Operating Companies (i.e., New York Bell, New England Bell,
Illinois Bell, etc.) AT&T owned Long Lines, Western Electric (its manufac-
turing arm), and Bell Labs, along with other miscellaneous companies, as
can be seen in Figure 3.

Western Electric, by itself, is the 22nd largest U.S. industrial
corporation ranked by annual sales, and sells between $12 and $13 billion
in equipment, mostly to Long Lines and the Bell Operating Companies.

Bell Labs is one of the world's largest industrial research and
development labs with an annual budget in excess of $1 billion. Bell Labs
has over 9,000 employees, 2,700 of whom are Ph.Ds.

D.   **The Settlement**

Settlement talks had been going on in earnest for only 6 weeks when
AT&T went to the Justice Department and suggested a "simple" resolution.
This became the basis of the 14-page settlement, which Judge Greene sub-
sequently modified. The main provisions of the Modified Final Judgement
are listed below.
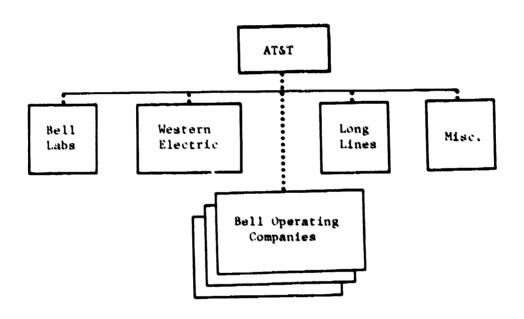
Figure 3

Presettlement Structure of AT&T

(1) The Settlement's Elements

a. AT&T must divest itself of <u>the local telephone service</u> provided the

22 Bell Operating Companies—the BOCs.

> Local service is the most costly to provide, and is expected to
> experience relatively slow growth in the next few years. Local
> service is said to receive cross-subsidies from revenues earned
> by AT&T Long Lines, and it is the service whose price is most
> rigorously regulated. Under the settlement, local service will
> probably continue to be regulated by the States, but it is
> important to note that much of the service currently provided by
> the BOCs is not considered local telephone service in the
> settlement. For example, most intrastate toll service, and the
> facilities used to provide that service, will be transferred
> from the BOCs to their former parent.

b. <u>Western Electric Bell Laboratories</u>, and <u>AT&T Long Lines</u> will be

retained by AT&T.

> As noted, most intrastate toll services currently handled by the
> Bell Operating Companies will be turned over to AT&T Long
> Lines. Consequently, AT&T will remain a near total monopolist
> in the provision of inter- and intrastate services, and will be
> in a position to provide many other telecommunications-
> information services. Western Electric will remain intact as
> the Nation's—and perhaps the world's—dominant telecommunica-
> tions equipment manufacturer. Bell Labs will also remain as an
> integral part of the AT&T system, providing research support to
> Western Electric, Long Lines, and other AT&T enterprises that
> are beginning to emerge, such as the consumer products subsid-
> iary, American Bell.

c. The substantive provisions of <u>the 1956 Consent Decree</u> will be

vacated.

> AT&T will no longer be barred from offering unregulated non-
> telephone services. This opens the way for the new AT&T to
> enter such areas as computer and data-processing communications
> (though electronic publishing will remain prohibited for 7
> years).

d. The Bell Operating Companies—those divested over the next 2 years by
    AT&T—will be required to provide <u>access to their facilities</u> for all
    long distance telephone companies on a nondiscriminatory basis.

e. Local telephone companies will be <u>barred from discriminating</u> against
    AT&T/Western Electric competitors in buying equipment and planning
    new facilities.

f. <u>AT&T shareholders will retain stock</u> in AT&T, and will be issued
    proportionate values of shares in the local exchange companies, which
    they can—at their choice—sell at any time.

g. <u>The Justice Department will have visiting and inspection rights</u> at
    the local operating companies to interview employees and review the
    books. This may be supplemented by state regulatory supervision.

The following elements are due to Judge Greene's modifications as outlined
in a 178-page document released on August 11, 1982:

h. The reorganization of the Bell System—and in particular the terms of
    the divestiture of the operating companies—can only be carried out
    with <u>Judge Greene's participation and oversight</u>.

        The Judge said that he wants to <u>review and approve</u> each step of
        the divestiture to make sure that the local operating
        companies—once divested—remain financially viable.

i. Other parties involved in the divestiture and in the antitrust suit
    generally can file for <u>"intervenor" status</u>.

        This means that they, too, can make their comments known to the
        Judge and the court during the divestiture and restructuring

process. These "intervenors," the Judge suggested, should include the Chief Operating Officers of the divested operating companies.

j.   There will be limits placed on the __amount of debt__ that the divested phone companies will inherit from AT&T.

k.   AT&T will be restricted from engaging in __electronic publishing__ over its own transmission facilities.

> The Judge defined electronic publishing as "the provision of any information that AT&T or its affiliates has, or has caused to be, originated, authored, compiled, collected or edited or in which it has a direct or indirect financial or proprietary interest and which is disseminated to an unaffiliated person through some electronic means." Upon a filing by AT&T, this restriction "shall be removed" after 7 years from the date of entry of the decree, unless "the court finds that competitive conditions clearly require its extension."

l.   The local telephone companies (BOCs) will be allowed to market, though not manufacture, __terminal equipment__ such as telephones and switchboards, and other sophisticated devices.

> Terminal equipment is a highly lucrative and—of late—rapidly expanding business area. (It was originally stimulated by FCC interconnect decisions of the late 1960s.) Under the original proposed settlement, the BOCs could not sell terminal equipment, which was to be an exclusive AT&T activity. Now Western Electric, AT&T's manufacturing arm, will have to supply the BOCs with equipment in competition with other equipment manufacturers. AT&T will also compete with the BOCs in the sale of equipment.

m.   The BOCs can publish the __Yellow Pages__.

> This is another profitable area that had—under the original agreement—been reserved for the parent AT&T. It will be worth $3 billion a year in revenues to the BOCs.

n. The BOCs can venture into <u>other unregulated business areas</u> as long as they can show that they will not use their monopoly power to hinder competition.

> This will pave the way for "unlimited" competitive options by the BOCs, such as data processing and many types of enhanced telecommunications services that the original settlement proposal would have barred. Indeed, AT&T wanted its divested operating companies to offer only regulated—and monopoly—local telephone service.

o. If equal access to long-distance competitors of AT&T is not given by a BOC, the rates charged by that company to long distance competitors such as MCI, SPCC, etc., should reflect the difference.

> In other words, <u>less than equal access will result in less than equal payment.</u>

p. If a BOC includes any charges on a <u>customer's bill</u> for services rendered by AT&T, the following statement must be included in the bill:

> "This portion of your bill is provided as a service to AT&T. There is no connection between this company and AT&T. You may choose another company for your long distance telephone calls while still receiving your local telephone service from this company."

(2) Why AT&T Settled

An understanding of AT&T's motivations for settling provides an insight to their future direction. Few believed that the company would be required by the Justice Department to divest any—let alone all—of its 22 operating companies. So why did AT&T settle? Why did the world's largest company decide to split itself into several different pieces, choosing to go for the newer, competitive telecommunications-information services

rather than the safe, regulated, but monopolistic local telephone service
with a guaranteed profit?

a.   AT&T decided to abandon local telephone service in favor of the

      newer, competitive, partially deregulated services because it is

      certain that it can win—and win big.

            It will have the ability to establish new monopoly power in
            areas that are dynamic, highly profitable, with low operating
            costs, and where demand is growing geometrically. Demand for
            voice service is growing at a so-so 8 percent per annum and is
            threatening to taper off, especially with the introduction of
            so-called measured use or usage sensitive pricing. AT&T Long
            Lines, which dominates long distance services, will no longer
            have to "subsidize" local exchange rates.

b.   Local telephone service is going to cost significantly more over the

      next decade.

            This will result in a greater degree of interest—and
            harassment—on the part of the state regulatory authorities.
            (This cost increase was happening irrespective of the
            settlement.)

c.   Recent legislative activity on Capitol Hill threatened to limit

      AT&T's ability to compete effectively in the newly emerging

      competitive markets.

            Most bills required the establishment of one or more separate
            subsidiaries to compete in new service areas, and fairly
            stringent regulation of noncompetitive services. In addition,
            legislation would keep AT&T out of specific business activities,
            i.e., mass media services, electronic advertising and
            publishing, etc. AT&T is extremely interested in broadband
            communications and electronic publishing, and also in the
            provision of a wide variety of entertainment, information, and
            business services.

d.   AT&T was uncertain as to future FCC regulation.

> Although FCC Chairman Mark Fowler is an avowed "unregulator,"
> there are certain decisions and potential decisions[1] that AT&T
> began to believe might impose undue competitive restrictions on
> the company as it exists today.

e.   AT&T began to see that it was "on the ropes" in the antitrust trial

in Washington, D.C.

> Judge Harold Greene, who in the summer of 1981 refused to
> dismiss the case, was clearly backing the Justice Department.
> AT&T, if found guilty by Judge Greene, could not have avoided a
> finding of liability which in turn would expose the company to
> enormous damage claims from a wide variety of its competitors—
> and even perhaps some of its customers.

f.   Possible court delays were beginning to frighten the people who

govern AT&T.

> Computer II and other cases involving AT&T were threatening to
> go all the way to the Supreme Court. These, plus further
> regulatory and legislative delays, forced AT&T to settle with
> Justice, restructure, and go aggressively for the new markets.

D.   Changes in AT&T's Structure over the Next Two Years

Two important dates will affect the future structure of the telecom-

munication-information industry and earmark the beginning of a new com-

petitive era:

●   The Federal Communications Commission's Computer II decision was

implemented on January 1, 1983.

> At that time ownership of all installed Customer Premises Equip-
> ment (CPE) passed to AT&T—due to a corporate decision by AT&T
> and not the FCC. Also on that date, AT&T's Baby Bell, now known
> as American Bell Incorporated (ABI), opened for business. The

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[1] Relating, for instance, to Computer II, Cellular Radio, Competitive
Common Carriers, the Uniform Sytem of Accounts, Bell System Purchases from
the General Trade Suppliers, Telco-Cable Cross Ownership, and the
provision of videotex services.

Bell Operating Companies (BOCs) will not be able to handle new
customer premises equipment (CPE) in 1983, although they can
install and maintain it under contract to American Bell for at
least 18 months, thanks to a waiver by the FCC.

• Under the terms of the Modified Final Judgment in the AT&T anti-

trust case, AT&T and the BOCs must be separated from each other

by February 24, 1984.

But the internal target date of AT&T and the BOCs for planning,
tax year, and accounting purposes is January 1, 1984—assuming
Federal District Court Judge Harold Greene approves. From that
date, there will no longer be any organizational ties between
the BOCs and AT&T. Also by that date, the BOCs, at their own
discretion, can move back into the marketing of CPE, but cannot
manufacture it.

In addition to local exchange functions, the BOCs can
operate AMPS (Advanced Mobile Phone Service), Yellow Pages, and
other competitive/deregulated business interests so long as
their monopoly local exchange revenues are not used for the
purpose of cross-subsidizing their competitive offerings. The
BOCs will not be able to offer intrastate interexchange toll
services. Also, because all CPE installed through 1982 is now
owned by AT&T, the BOC's will not be permitted to service it.
In 1984, AT&T Long Lines will become known as AT&T Inter-
Exchange (AT&T IX) and will offer interstate, intrastate, and
international toll telecommunications traffic.

1. AT&T in 1983

In 1983, AT&T's corporate structure will include Bell Laboratories,

Western Electric, Long Lines, AT&T International (ATTI), Advanced Mobile

Phone Service (AMPS) and American Bell (ABI). It will also continue to

control the destiny of the Bell Operating Companies during this important

transitional period. The transitional AT&T structure is outlined in

Figure 4.

During 1983, AMPS will be a division of AT&T and will be able to

offer cellular radio services in those markets in which it has been

granted FCC permission to operate. AMPS will also sell and manufacture
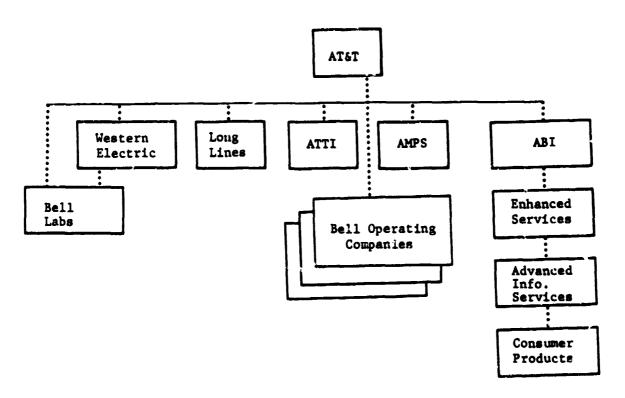
Figure 4

AT&T's Structure in 1983

equipment (perhaps via Western Electric), and offer technical and service assistance.

American Bell will begin operations with three important divisions: Advanced Information Systems; Enhanced Services and Data; and Consumer Products. Its equipment will be purchased from Western Electric and also from other suppliers. It plans to sell equipment via its own telephone stores and also under an agreement with Sears.

The other divisions of the company--Bell Labs, Western Electric, Long Lines, AT&T International and the BOCs--will operate as they did in 1982, except that the BOCs will begin to plan their restructuring into seven regional operating companies and will lose the ability to sell new customer premise equipment (unless there is some last minute change in AT&T's CPE plans). AT&T Long Lines will also be going through some organizational changes as it looks toward taking over all interexchange traffic following the divestiture of the BOCs.

2. AT&T in 1984

By 1984, the AT&T reorganization will have been completed. AT&T will have spun off the seven regional BOCs and will be left with: Bell Labs and Western Electric, which will be very closely linked; AT&T Inter-Exchange (AT&T IX); the Embedded Base Organization; a dramatically reduced Advanced Mobile Phone Service (AMPS) organization; AT&T International (ATTI); and American Bell (ABI). The reorganized AT&T structure is outlined in Figure 5.

The Embedded Base Organization will be a totally new division of AT&T in 1984, and its future is currently uncertain. It will probably be limited to marketing and sales.

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                                   ┌─────────┐
                                   │  AT&T   │
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   ⋮           ⋮              ⋮           ⋮          ⋮                ⋮
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│         │ │ Western  │  │ ATTIX  │  │ ATTI   │ │ AMPS*   │    │  ABI    │
│         │ │ Electric │  └────────┘  └────────┘ └─────────┘    └─────────┘
│         │ └──────────┘                   ⋮                        ⋮
   ⋮           ⋮                           ⋮                    ┌─────────────┐
┌──────────┐                          ┌──────────────┐         │ Enhanced    │
│ Bell     │                          │ Embedded Base│         │ Services    │
│ Labs     │                          │ Organization │         └─────────────┘
└──────────┘                          └──────────────┘              ⋮
                                                            ┌─────────────┐
                                                            │ Advanced    │
                                                            │ Info.       │
                                                            │ Services    │
                                                            └─────────────┘
                                                                  ⋮
                                                            ┌─────────────┐
                                                            │ Consumer    │
                                                            │ Products    │
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* Reduced from 1983.
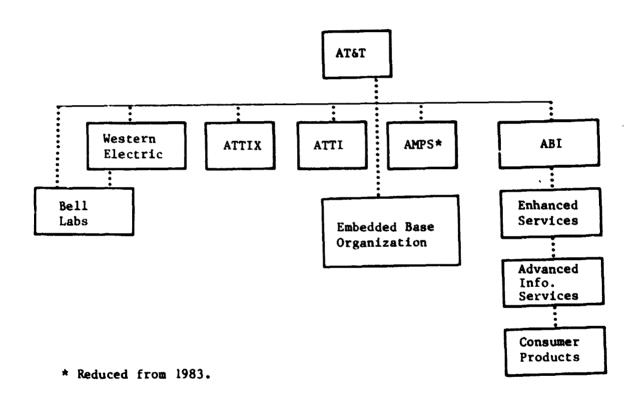
Figure 5

AT&T's Structure in 1984

BSPPD (the Bell System Product Procurement Division), the centralized
purchasing entity for the Bell System, is already being phased out of
existence and will cease to exist in 1984. Some of its people will be
moved to American Bell (some have already been transferred), while others
will go to the regional staffs and the central staff of the BOCs.

ATT IX will take on greatly expanded business responsibilities in
1984 as the company begins to offer intrastate interexchange services in
addition to the interstate and international offerings that it currently
handles. AT&T IX will be vertically integrated with Western Electric,
Bell labs, and American Bell. AT&T International and American Bell will
remain unchanged.

3.   The New Western Electric

Western Electric and Bell Labs will continue to be closely related.
Western will offer a full range of equipment, at least for the time
being. There may be some production changes down the road. Its range of
equipment offerings may be narrowed due to competition from other equip-
ment suppliers, but the future is too uncertain at this stage to make any
definite predictions as to its future equipment manufacturing range.

Western Electric will have important business relationships with six
major entities:

- **Bell Labs and AT&T IX**: Western will provide the vast majority
  of AT&T IX's equipment needs.

- **AT&T International**: Western will vigorously pursue interna-
  tional sales and international joint ventures, under the
  umbrella of AT&T International.

- The seven regional Bell Operating Companies and the companies that make up those regional BOCs: Western wants to maintain its close ties with the divested operating companies.

- American Bell, Inc.: Western wants to be the major provider of equipment to its sister division, ABI, and will attempt to move closer to this division. There may be problems in this relationship, however, since ABI may want to make its own decisions and choose to remain independent of Western.

- The end user for customer premise equipment: Since Western has a good name in the equipment manufacturing business, but has hitherto lacked national marketing expertise, it may face problems here. Nonetheless, it is planning a major national advertising campaign and AT&T's marketing venture with Sears will help it remain close to the residential user. Western plans to beef up its contacts with the business user, especially the Fortune 500 companies.

- The Independent Telephone Companies: United Telecommunications, Continental, CENTEL, and Mid-Continent are all potential customers. On the other hand, Western expects to sell very little equipment to GTE, which is vertically integrated and manufactures most of its own equipment.

The independent manufacturers of equipment--those belonging to the general trades suppliers--may have little contact with Western Electric post-divestiture, and will have no contact whatsoever with Bell Labs. The independent equipment manufacturers will therefore find themselves competing even more vigorously with Western, and will have to establish new and closer business contacts with the BOCs, American Bell, AT&T International, and the end user (both business and residential).

4.   The BOCs in 1984

In 1984, the BOCs will become seven different units, and their organizational structure will look significantly different from presettlement days when the BOCs were closely integrated into the overall vertically integrated AT&T corporate structure. The reorganized BOC structure is outlined in Figure 6.
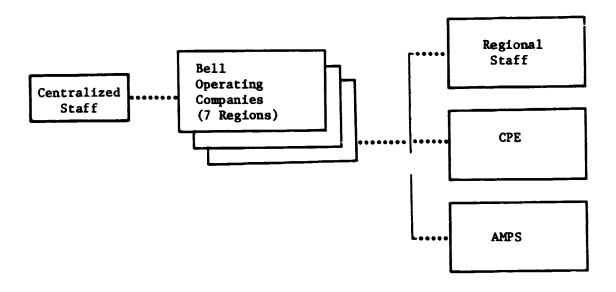
Figure 6

Bell Operating Companies in 1984

A Central Staff Organization will be created by the seven BOCs. It
will be responsible for network engineering. This staff will not serve as
a central purchasing organization for the seven companies. If it does,
the general trades suppliers will probably take the seven BOCs to court on
antitrust grounds. The seven companies, since they are large organiza-
tions in their own right, are expected to do their own purchasing. There
will also be significant unilateral action permitted on the part of the
separate members of the regional BOCs--Illinois Bell, Michigan Bell,
etc.--to allow them some flexibility in equipment purchases.

The Regional Staff for each of the seven regional BOCs will have the
capability of performing technical and economic evaluations. The staff
will establish purchasing and distribution capabilities, but--as mentioned
above--so can the individual companies that make up the regional com-
panies. There will be some degree of independence between the companies
that make up a regional BOC.

The seven regional companies--according to the terms of the Modified
Final Judgment--will not be dependent upon any given equipment supplier,
and in particular Western Electric. Western Electric will be just a.·other
supplier, although it will be the major one--at least for a few years.

Under the terms of the antitrust settlement, the seven BOCs will be
able to return to the CPE business in 1984. They will be able to market--
though not manufacture--CPE at their own discretion. There is an expecta-
tion that some BOCs will decide to return to the CPE business and some
won't: some BOCs will offer a wider range of equipment than others.

Whatever happens, the BOCs will not have an established CPE base because that stays with AT&T. Also, because of the antitrust settlement, it is not clear whether or not the BOCs will have to establish a separate subsidiary to handle new CPE, as they were originally required to do under the terms of the Computer II decision. Computer II was decided by the FCC before the Bell System was split up, so the separate subsidiary concept might be abandoned.

AMPS will be handled by the BOCs in 1984. The regional companies, which are only just beginning to be organized, have not decided how they will handle cellular radio, but decisions on cellular radio's future will be made over the next 12 months.

5. __Summary__:

- The structure of the telecommunications-information industry will change dramatically over the next 12-24 months.

- The markets for telecommunications services and equipment are also changing because of the AT&T antitrust suit settlement and also because of the FCC's Computer II Decision.

- American Bell began operations on January 1, 1983. It is going to be the primary AT&T marketer of CPE and the sole AT&T marketer of "enhanced" communications services.

- AT&T Long Lines is being significantly restructured and enlarged to become AT&T IX--Inter-Exchange. It will be vertically integrated in the new AT&T structure and will have close ties to Western Electric and Bell Labs, and perhaps even American Bell.

- The points of contact for Bell System customers and suppliers
  will be changing over the next 12-24 months.

- The seven regional Bell Operating Companies--once divested--will
  gain some new responsibilities, e.g., cellular radio and perhaps
  some competitive business activities--but will lose others,
  e.g., intrastate toll and CPE (CPE for only a year if they so
  choose).

- Western Electric will vigorously attempt to protect, and even
  enlarge, its markets. It will have close ties to Bell Labs,
  AT&T IX, American Bell, the BOC's, and others.

- All of this activity may result in massive confusion over the
  next couple of years--for users, for equipment vendors, and for
  telecommunications service providers.

E. Remaining Issues Relevant to NASA

Although the Judge approved the settlement, with his modifications
included, there are still a number of critical issues that will remain
unresolved for some time, especially since it will take AT&T at least 2
years to reorganize. Clearly, the turmoil is not over. Many decisions
are yet to be made which will determine the future structure of the
industry. In the longer-term, these industry structure changes will lead
to price and technology changes. And these changes will in turn impact
NASA's costs and options. The following are specific examples of
important remaining issues:

1. The FCC's activities in the interim as AT&T attempts to reorganize
    may dramatically influence the shape of future competition. It seems
    clear that the Commission will continue to play an important role.
    Plans already exist to launch a major inquiry that will examine the
    implications of the settlement. The Commission will do this under
    Section 214 of the Communications Act which gives it authority to
    certify the transfer of assets. The indications are that the FCC
    will plan one comprehensive proceeding dealing with a miscellany of
    AT&T settlement problems and issues.

2. What does the U.S. Congress plan to do this session? There will
    certainly be a series of hearings relating to the settlement—and
    also to other telecommunications-information industry structure and
    policy issues. But there may also be a series of bills relating to
    certain aspects of the settlement, although Senator Bob Packwood,
    R-OR, Chairman of the Senate Commerce Committee, and Congressman
    Wirth have both stated intentions to wait on major legislation until
    the settlement is implemented and any remaining problems become
    clear.

3. The types of restraints the State Regulatory Commissions are likely
    to place on the BOCs' competitive activities are unknown, as is the
    FCC's part in the process of allowing the BOCs to get into competi-
    tive areas.

4. The so-called access problems remain in spite of Judge Greene's
    attempts to mollify those who will compete with AT&T Long Lines. The
    rates charged for access—and less than equal access—will be debated
    "in perpetuity," according to some experts. Again the FCC, and
    perhaps the Congress, will be involved in the process.

5. Confusion remains over whether AT&T and the divested BOCs will be
    allowed to move into cable television or other interactive services
    via broadband facilities. Where the BOCs are concerned, FCC rules—
    at least for the time being—prevent them from entering cable,
    although Judge Greene obviously wants the BOCs to compete in other
    areas and did not specifically bar them from cable. Nonetheless, the
    FCC, as authorized by the Communications Act of 1934, has primary
    jurisdiction over telecommunications policymaking. Where AT&T is
    concerned, it appears that the cable business is open to it, along
    with other "local distribution" options, although some policy experts
    believe that Judge Greene's "broad definition" of electronic publish-
    ing may keep AT&T out of the business for 7 years.

6. There is growing uncertainty about what exactly constitutes elec-
    tronic publishing, and many policy experts believe that this uncer-
    tainty can only be resolved either by the FCC or the Congress. A new
    Computer II type inquiry may be necessary except that this time the
    argument will be about what is, and what is not, electronic publish-
    ing. A leading question here is: Can electronic publishing be
    separated from the new data services such as teleprocessing? This
    may develop into a serious problem for AT&T.

CHAPTER FIVE: THE FCC AND NTIA

A.   FCC Activities

Throughout all of the deliberations concerning the AT&T settlement, the FCC will remain the dominant policymaking body, not only regarding the future of AT&T but also in a host of other matters.

The Commissioners and senior staff at the FCC have been preoccupied with the post-AT&T settlement problems that they fear they will be called upon to resolve. But because of severe budgetary constraints imposed upon it by the Reagan Administration, the FCC may be losing its ability to regulate as effectively as it has in the past. In addition, the FCC has scaled down the size of its policy planning capability. The Commission is now apparently ill-equipped either to regulate effectively or to conduct meaningful policy planning in new policy areas. The result, apparently, will be a progressively heavier reliance on the marketplace.

1.   Regulatory Surveillance and Rate-Setting

The FCC has changed the thrust of its regulatory approach. Emphasis has shifted from detailed cost surveillance, particularly of cost allocation on a service-by-service basis, to broader review processes which are to complement the FCC's basic reliance on "market forces" as a means of keeping prices just and reasonable. Thus, those unhappy with the treatment they are getting from the FCC must look to the market, and, if this does not work, to the Courts and Congress as a means of advancing their interests. Clearly, the Specialized Common Carriers and many of the users will have to take this route.

The FCC is backing away from the vigorous service-by-service fully distributed costing standard that it established in 1976, known as Fully Distributed Cost Method 7.

The Commission is also deemphasizing its goal of carrier accountability. For example, in April 1980, in a proceeding involving determination of access charges for exchange network facilities, the Commission decided it could regulate charges by considering cost allocations for only four broad interstate service categories.

Also, in June 1980, in a decision involving the Fully Distributed Cost manual, the FCC found that only an overall (e.g., private line) service category must earn the Commission's prescribed rate of return, rather than each private line service. In short, rates for individual services would not be closely scrutinized.

The FCC is relying increasingly on current-relative-use or separations-based allocations for any surveillance activities that remain. This is a significant step away from the forecast-based allocations mandated by the FCC in 1976. It is recognized that in order to implement the necessary changes, revisions to the Uniform System of Accounts are essential, but these have been put on the back burner with no meaningful result expected until 1985.

The Commission has therefore substantially reversed its prior policies, which were designed to closely monitor the costs of competitive services offered by AT&T in order to make sure that there was no cross-subsidization or predatory pricing. Fully Distributed Cost Method 7 has been abandoned, and separations categories and principles underlie the Commission's new cost approach. The FCC's interim cost allocations

manual, adopted in December 1980, and its development of access charges in
an earlier proceeding, both rely on cost allocations and earnings devel-
oped for broad service classes, not for individual service offerings. In
Phase I of the Competitive Common Carrier Docket, decided in August 1980,
the Commission indicated that nondominant carriers' tariff proposals may
no longer require service cost support materials. The final phase of this
docket may be decided in early 1983.

All of this means that AT&T has been given much greater ratemaking
discretion. It can set prices and distribute costs for particular ser-
vices within an overall service category according to its own marketing
strategy. When and if these plans break down, the Commission will resort
to the negotiations process—in the same way that it fostered interstate
access charges. Recent Joint Boards also illustrate this more informal
approach.

Of course, it remains to be seen whether or not this additional
discretion will have an adverse impact. If the theory of the settlement
is correct (see Chapter 4 above), the divestiture of competitive/
unregulated businesses from AT&T has largely eliminated the incentive to
cross-subsidize. Unless it turns out that some of the businesses retained
by AT&T are not workably competitive, market forces can be expected to
control prices effectively. The FCC's shift in cost standards can there-
fore be regarded as allowing a test of whether or not the market will
work.

FCC Chairman Mark Fowler essentially had no choice but to curtail
rigid regulatory oversight, largely because of budgetary constraints, but
also because of the loss of key personnel (partially due to burgeoning

opportunities in the private sector) and the Reagan Administration's
regulatory (or unregulatory) philosophy. In financial and accounting
areas, therefore, a higher earnings level and new higher depreciation rate
prescriptions are permitting earlier recovery of capital and higher rates
for AT&T. As a result, AT&T is garnering higher cash flows with which to
pursue substantial investments in competitive enhanced services, terminal
equipment, and network construction.

2. Common Carrier Issues

The FCC will press ahead—regardless of the settlement of the AT&T
suit—with attempts to allow marketplace forces to restructure the
telecommunications-information industry as opposed to regulatory
restraints. Computer II implementation, now that the decision has been
upheld by the D.C. Circuit Court of Appeals, is being given top priority,
not only within the Commission, but also between the Commission and the
State Regulatory Commissions. The so-called nondominant carriers will be
freed from much regulation when the Competitive Common Carrier Docket
comes up for final consideration; a new private line rate structure will
be devised; and attempts to revise the 46-year-old Uniform System of
Accounts will continue. The so-called Interim Cost Allocations Manual
will attempt to determine what each group of telecommunications services
offered by AT&T really costs; changes will be instituted in the separa-
tions and settlements procedures in order to protect the small and rural
telephone companies; and significant progress is expected regarding the
development of local access charges. In addition, there will be further
work in establishing proper depreciation procedures for all carriers, an

inquiry into domestic satellite spacing, and an inquiry into the proposed

deregulation of domestic satellites. The Commission may begin a rulemak-

ing into telephone-cable cross ownership, will continue to implement the

Cellular Radio Decision by awarding licenses to operate, give the go-ahead

to Digital Termination Service (local distribution), and establish policy

regarding videotex-viewdata.

On the international side, the Senate's recent deliberations on

S.2496, the "International Telecommunications Deregulation" bill, have

influenced the FCC's actions. The Commission has abandoned its so-called

Authorized User Decision, which means that users (including NASA) will be

allowed to obtain some services directly from COMSAT rather than going

through AT&T or the International Record Carriers (IRCs). In addition,

regional satellite policies are also being encouraged, including a recent

transborder accord reached with Canada. This coincides with the imple-

mentation of more competition in the international telecommunications

service arena as Western Union is allowed to compete internationally with

AT&T and the International Record Carriers (IRCs), while the IRCs will be

allowed to compete domestically with Western Union. Also, the FCC will

look into international trade reciprocity in the area of telecommunica-

tions equipment purchases, although such "sectoral" reciprocity is

unlikely to be implemented. Nonetheless, telecommunications trade policy

issues will certainly be on the congressional agenda.

B.   NTIA Activities

Current budgetary constraints which have reduced the National Tele-

communications and Information Administration's appropriations are part of

a several years old trend toward reducing the government's role concerning

the planning process in the telecommunications industry. NTIA's planning and policy activities are being greatly reduced and its Boulder group (where most of this work was done) has been eliminated. Furthermore, it will no longer be involved in the planning and procurement of federal agency telecommunication systems. NTIA will focus its efforts on the international policy area, spectrum management and networks research and analysis.

In the short-run, industry may notice little change, but NTIA has been a rich source of advice for the FCC and with the FCC's own budget-strained, long-range planning expertise is sure to suffer. With recent efforts towards deregulating portions of the industry, the need for exten-sive detailed oversight is diminishing, but in such a complex and dynamic industry as telecommunications, constant vigilance is required to ensure the proper functioning of the marketplace and its relationship with those sectors still regulated.

The rapidly changing telecommunications environment and the concurrent de-emphasis on long-range planning at NTIA and the FCC make it necessary for each agency to assume a greater share of the responsibility for assuring that such policies are adopted as will provide for the availability of reliable cost-effective communications. This means that NASA's communications personnel will need to make every effort to keep abreast of the technological changes in the industry, the regulatory decisions impacting the telecommunications environment, and the long-range implications which such changes may have on NASA.

CHAPTER SIX: IMPLICATIONS FOR NASA

Implication #1:   Conceptual planning for the telecommunication networks

is becoming increasingly important.

As competition in the telecommunications industry increases and tech-

nology advances, the network managers will find that available services

and equipment will become more diverse, and along with the various rates,

are likely to change more frequently. Also, the number of offerers will

increase, since there are likely to be more "piece-part" suppliers emerg-

ing to capture market niches and more "end-to-end" vendors emerging to tie

the many new offerings together into communications packages transparent

to the user. Within this rapidly changing environment there will be a

greater tendency for the network planners to optimize their piece of the

network "locally" (as each new requirement or offering comes into exist-

ence) rather than "globally" (i.e., for all of NASA, in the longer-term).

This tendency will lead to unnecessary inefficiencies if decisions to make

or forego procurements are not made within the guidelines of a long-term,

conceptual plan for the networks. It is easy to conceive of procurements

which appear to be cost-effective today, but which limit the neworks'

options and flexibility and force less cost-effective procurements in the

future. Most of this potential problem can be avoided if a formal

description of where the networks are headed is developed and if communi-

cation amongst the various network planners (and between the planners and

the user community) is improved.

Implication #2: Comprehensive, up-to-date information on available

equipment, services and rates are becoming increasingly

important.

As was mentioned in Implication #1, the pace of introduction of new

equipment and service offerings appears to be accelerating. And, as AT&T

enters new unregulated markets and competition increases, the number and

frequency of rate changes will increase. Rates will also be in flux due

to the divestiture and the (unrelated) move towards cost based pricing,

which will result in reduced long distance rates and increased local

rates. Many of these changes could lead to reduced costs, but in order

for NASA to take advantage of these myriad opportunities, the network

managers must have comprehensive, up-to-date information. An advanced

decision-support information system, which can provide comprehensive

information on opportunities as well as information on NASA's current and

future requirements, can keep management sensitive to the changing

environment and can help management make the most efficient decisions

possible.

Implication #3: Interaction with the telecommunications environment in

which it must operate is becoming increasingly important

to NASA.

There are, and will continue to be, many changes in telecommunica-

tions policy which will impact NASA. But NASA can influence the direction

of such changes and, if properly prepared, can benefit from (or at least

minimize the effects of) those changes. Technologically, NASA has had a

great impact on the development of the telecommunications systems upon

which it currently relies. It has, however, chosen to remain virtually

inactive in the development of telecommunications policy domestically.

This reactive role in policy development is not the only available option,

as evidenced by NASA's success in the development of telecommunications

policy and standards within the international arena. This success is, in

a large part, due to the fact that many NASA employees hold national and

international posts within international organizations. As a result, NASA

is able to be intimately involved in the policymaking (or standards

setting) process. Although there is little chance that this level of

success could be achieved in the domestic process, the current environment

is creating possibilities. The increasingly competitive industry, a

dynamic regulatory environment, the increasing importance of data distri-

bution to the performance of NASA's missions, and the declining role of

NTIA and the FCC in the formulation of telecommunications policy, all

interact to create a situation in which NASA will benefit from choosing a

more positive, active position.

CHAPTER SEVEN: RECOMMENDATIONS

The implications presented in the previous chapter pointed to the importance of: 1) long-range conceptual planning for telecommunications networks, 2) comprehensive up-to-date information on new offerings in the telecommunications industry, and 3) efforts to interact with the telecommunications regulatory environment. Provided below is a set of recommendations which parallel these three implications, as well as a fourth recommendation which, if enacted, will enable NASA most effectively to implement the three other recommendations.

We recommend that a position be created within the Office of Space Tracking and Data Systems (OSTDS), the responsibilities of which are listed in Recommendation #4. Our observations of OSTDS activities throughout the 9-month duration of this study led to the conclusion that the activities detailed in Recommendations 1, 2 and 3 are not properly provided for within the existing organization because of their secondary or "extra detail" status. In the existing and future telecommunications environment, NASA will benefit greatly if these activities are pulled together at a single point, creating a new position with responsibility for both long-range planning and telecommunications policy analysis. Given the subtlety of political trends and the many minute but significant details in proposed regulatory change, only an individual familiar with the preferred options for satisfying NASA's long-range telecommunications requirements can recognize all the potential future options foreclosed by the decisions made today. Likewise, only an individual acquainted with both political and technological trends deduced from informal industry

contacts and comprehensive up-to-date data can properly maintain a long-range conceptual plan for the totality of NASA's information requirements.

Recommendation #1: Planning Activities

    1A.   Develop and maintain a long-range conceptual plan for all of NASA's information requirements. To assist in this task, a working group should be formed consisting of both Headquarters and Center personnel with expertise in data sys :-s, telecommunication network capabilities, and future prog:&⌐ requirements. The conceptual plan should be based on the projected regulatory and technological environment rather than that exist-ing at the time, and on possible and probable infor ation requirements rather than just approved and funded requirements as currently stipulated in NMI 2520.1C (which guides the activities of the Communications Planning and Analysis Branch of the NASCOM Network Directorate at GSFC). The Space Tracking and Data Systems Division is currently considering procuring the services of an outside consulting firm to develop just such a conceptual plan. If this is done, the working group should have the responsibility of maintaining the plan.

    1B.   Push for the completion of NSDP Section II, the 5-year develop-ment plan for the NASCOM system. A similar development plan should be completed and maintained for the Program Support Communications system. It is important to recognize that these are intermediate range plans and are not a substitute for the longer-term conceptual plan.

1C. <u>Improve the incentives for communication amongst the network</u>

<u>planners</u>. Participation in the process of maintaining an over-

all conceptual plan will encourage this exchange of ideas and

expertise.

1D. <u>Encourage, and expand where possible, the ongoing planning-type</u>

<u>activities</u>, such as the Data Systems '90 study and the 10-Year

Frequency Requirements study.

<u>Recommendation #2: Decision Support System</u>

2. <u>Develop and maintain the following data bases, integrated to comprise</u>

<u>a useful management decision support system.</u>

2A. Management level data on new service and equipment offerings.

2B. Current regulatory issues, the possible impacts of such on NASA,

the NASA position on each issue and an account of any responses

made (or in progress).

2C. An official mission model projecting information requirements at

least 10 years into the future.

2D. A communications and data systems user community profile.

2E. A complete set of documents relevant to the telecommunications

environment in which NASA must operate (e.g., legislation,

dockets, NMI's, OMB Circulars, industry reports, etc.).

Recommendation #3: Interacting with the Environment

3.   NASA should move towards a more active role in the development of
     telecommunications policy domestically.

     3A. Continue to familiarize itself with the telecommunications
          policymaking process and with the leading policymakers them-
          selves. It should meet at all levels with the FCC, NTIA, OMB,
          GSA, the White House and the Departments of Defense, Justice and
          State. Contacts should be established and areas of mutual
          interest explored. Also, contacts should be established with
          the pertinent State Regulatory Commissions.

     3B. Make itself available to the appropriate committees of Congress
          as an expert in the telecommunications technology field. As
          well as playing an active role in legislative hearings pertinent
          to telecommunications technology and policymaking, NASA should
          offer its expertise informally to key politicians and staffers.
          Likewise, NASA should more frequently offer its expertise to the
          FCC as it deliberates on numerous proceedings of consequence to
          NASA and NASA's contractors.

     3C. Improve the existing mechanisms for reviewing and responding to
          FCC Dockets and Congressional Inquiries and other materials
          related to telecommunication policy. Several NASA responses
          were initiated by the authors during the course of this study,
          allowing first-hand exposure to the process (see Appendix D).
          We found the existing response mechanisms to be virtually use-
          less from the standpoint of influencing telecommunications
          legislation or rulemakings. The Office of Legislative Affairs

(Code C) is oriented towards the budgetary process and is ill-
equipped to recognize the importance or relevance to NASA of
subtle technological issues. Nor do they maintain active con-
tacts with the telecommunications subcommittees. As a result,
too many items of potential significance fall through the
cracks. When and if the information does get to the Communica-
tions and Data Systems Division there is little that can be done
with it. Time lines are too short, the clearance process for
responses is too long, managers do not have the time and are not
trained to be sensitive to the political subtleties, and the
informal contacts with the policymakers are almost nonexistent
(outside of Code C and its budgetary activities). A set of
issues and response guidelines, updated periodically to reflect
contemporary requirements, would help reduce the reply time (see
Recommendation 2B) and, perhaps most importantly, the establish-
ment of informal contacts between the Office of Space Tracking
and Data Systems and the policymakers would improve the informa-
tion flow (see Recommendation 4A). Currently, NASA is "concur-
ring," through silence, to testimony on both sides of important
issues, allowing others (e.g., DOD) to "carry the ball."

Recommendation #4: Planner/Policy Advisor Position

4.   A long-range conceptual planner/telecommunications policy advisor
     position should be established within the Office of Space Tracking
     and Data Systems. Representative responsibilities for such a posi-
     tion are given below.

4A. Communication systems long-range conceptual planning.

    4.A1 Develop and maintain a long-range conceptual plan as

          described in Recommendation 1A.

    4.A2 Initiate and chair a NASA-wide working group which will

          assist in the maintenance of the plan.

    4.A3 Provide guidance and oversight for the planning officers of

          each network, develop incentives for improving planning

          dialogue amongst NASA offices, and encourage and coordinate

          planning efforts by NASA's frequency, network and data

          systems managers.

    4.A4 Initiate and improve efforts to identify long-range com-

          munication systems requirements as inputs to the planning

          process (see Recommendation 1D).

    4.A5 Stay apprised of new service offerings, tariffs and equip-

          ment and their potential usefulness to NASA in the long

          term (see Recommendation 2).

4B. Telecommunications Policy Advising.

    4.B1 Provide a single NASA point of contact for all telecommuni-

          cations regulatory and policy issues.

    4.B2 Provide impact analyses of new and pending telecommunica-

          tions policies.

    4.B3 Develop policy positions on issues relevant to NASA's

          communications interests.

    4.B4 Provide telecommunications policy advice to the Associate

          Administrator of the Office of Space Tracking and Data

          Systems.

4.B5 Develop congressional testimony on the implications for

NASA's communication systems of changing technologies and

policies (see Recommendation 3B).

4.B6 Respond in the telecommunications regulatory/legislative

fora according to the requirements of NASA's long-range

plan (see Recommendation 1).

4.B7 Keep apprised of relevant activities of the FCC, NTIA, GSA,

OMB, the White House and the Departments of Defense,

Justice and State.

4.B8 Keep apprised of the relevant activities of the State

Utility Regulatory Commissions (they will be increasingly

important).

4.B9 Collect and distribute relevant materials including Bills,

Dockets, congressional testimony, NASA NMI's, OMB

Circulars, industry reports, etc. (see Recommendation 2F).

4.B10 Develop productive contacts in the telecommunications

policy field outside NASA.

Note: There are of course many other planning and policy analysis

responsibilities which would necessarily fall under the purview of this

position, but which the authors of this report are not qualified to

detail. Also, it is recognized that there exist several alternatives for

implementing the above recommendations other than the creation of a new

position. However, it is necessary that NASA recognize the importance of

improving its planning efforts, enlarging its information base and

actively participating in the telecommunications environment in which it

must operate.

APPENDIX A
THE TELECOMMUNICATIONS-INFORMATION INDUSTRY STRUCTURE

Common Carriers

AT&T
GT&E
United Telecommunications
Continental Telecommunications
Central Telephone and Utilities
Mid-Continent Telephone
Rochester Telephone
        plus 1400 other U.S. independent telephone companies
Western Union

Specialized Common Carriers*

1. **Terrestrial**

    MCI
    SPCC (recently acquired by GT&E)
    USTS (IT&T)

2. **Satellite**

    American Satellite (Fairchild Industries and Continental
        Telephone)
    Comsat General
    RCA Americom
    Satellite Business Systems (IBM-Comsat-Aetna)
    Western Union
    AT&T
    GT&E
    SPCC
    Hughes

3. **Value Added Networks**

    ACS (Advanced Communications Systems-AT&T)
    Graphnet (Graphic Scanning)
    IT&T Domestic Transmission
    GT&E-Telenet
    Tymnet (Tymshare)
    Uninet (United Telecommunications)

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* Parenthesis indicate the ownership of subsidiaries, or national
  affiliation.

International Telecommunications

        IT&T Worldcom
        RCA Globcom
        TRT (United Brands)
        Western Union International (recently acquired by MCI)
        AT&T
        Comsat

Equipment Manufacturers

1. ### Major Equiment Suppliers

Western Electric (AT&T)	Automatic Electric (GT&E)
IT&T	LM Ericsson (Sweden)
Nippon Electric (Nippon T&T)	Northern Telecom (Bell Canada)
Philips (Netherlands)	Siemens (Germany)
Stromberg-Carlson (General Dynamics)	TRW/Vidar
	Plessey (Britain)
Wescom (Rockwell)	Thomson (France)
CIT-Alcatel (France)	General Electric of Britain

2. ### Microwave and/or Satellite Communications Equipment Vendors

Aydin	California Microwave
Comtech	Farinon
M/A-Com	Scientific Atlanta
Hughes	Ford Aerospace
	RCA

3. ### Other

American Telecommunications	Rockwell-Collins
Harris*	Motorola
Plantronics	Rolm
Telesciences	General Electric
Eatman Kodak	RCA
Zenith	Bell and Howell
Sony (Japan)	Thorn (Britain)
EMI (Britain)	Sanyo (Japan)
Sharp (Japan)	

4. ### Fiber Optic Manufacturers

AT&T	Corning Glass
IT&T	Times Fiber (Insilco)
Valtec (M/A-Com)	Fijitsu and other overseas manufacturers

---

* Currently being purchased by Western Union.

Computer, Data Processing and Communications, Office of the Future

IBM	Burroughs
NCR	Control Data
Sperry	Honeywell
Hewlett-Packard	Memorex
Data General	Xerox
TRW	Texas Instruments
General Electric	3M
Northern Telecom (Bell Canada)	NEC (Japan)
Wang	Pitney Bowes
Raytheon	Others in Western Europe, Japan
	and S.E. Asia

Mobile Communications Operators

1. **For Hire**

   A. **Radio Common Carriers (RCC's)**: Approximately 1,000.
   B. **Wireline Carriers**: AT&T and the other telcos.

2. **Private**

   Aviation and Marine; Public Safety; Land Transportation;
   Industrial; Personal: Thousands

Major Mass Media/Multimedia Companies

ABC	Capital Cities
CBS	Cox
Dow Jones	Gannett
General Electric	Harte-Hanks
Hearst	Knight Ridder
McGraw-Hill	Post-Newsweek
RCA (NBC)	Scripps-Howard
Time Inc.	Times-Mirror
Warner Communications	Westinghouse-Teleprompter

APPENDIX B
INDIVIDUALS INTERVIEWED

Dr. Walter Bolter, Chief Economist, House Telecommunications Subcommittee.

Tom Campbell, Associate Executive Director, FCC.

Cristopher Coursen, Counsel, Senate Telecommunications Subcommittee.

Gary Epstein, Chief, Common Carrier Bureau, FCC.

Jerry Fritz, Legal Assistant to FCC Chairman Mark Fowler.

James Graf, Legal Assistant to FCC Commissioner Joe Fogarty.

Bert Halprin, Division Chief, FCC Common Carrier Bureau.

Larry Harris, Chief, Broadcast Bureau, FCC.

Dale Hatfield, Consultant, formerly Associate Administrator, NTIA.

Leon Kastenbaum, Deputy Chief, FCC Common Carrier Bureau.

Dr. Dan Kelley, Office of Plans and Policy, FCC.

Dr. Jerry Lucas, President, TeleStrategies.

Dr. Kent Nilsson, Legal Assistant to FCC Commissioner Henry Rivera.

Scott Rafferty, Counsel, House Telecommunications Subcommittee.

John Rowe, MCI.

Commissioner Stephen Sharp, FCC.

Dr. Christopher Sterling, Special Assistant to FCC Commissioner Anne Jones.

Dr. Richard Thayer, AT&T, Corporate staff.

Phillip Verveer, Partner, Pierson, Bell and Dowd, formerly head of the
    Justice Department's Trial Staff in the AT&T antitrust case and
    formerly Chief, Common Carrier Bureau, FCC.

Paul Wickrie, Uninet, United Telephone.

Richard E. Wiley, Manging Partner, Kirkland and Ellis, former Chairman,
    FCC.

Dr. Raymond Willmotte, Office of Chief Scientist, FCC.

APPENDIX C
MEETINGS ATTENDED FOR THE STUDY

● TeleStrategies, Conference on the AT&T Settlement

● Department of Commerce, Conference on Information Policy

● Congressional Hearings on such topics as the 1934 Communications Act,
  International Telecommunications Deregulation, the AT&T/DOJ Antitrust
  Settlement, High Definition Television, and Advanced Satellite
  Communications Technology

● George Washington University, Course on Telecommunications Policy

APPENDIX D
NASA RESPONSES INITIATED BY AUTHORS DURING THE STUDY

- Response to Congressional inquiry on HR5158, "The Telecommunications Deregulation Act of 1982."

- Systematics General Corporation study of the impacts of several legislative initiatives on the TDRSS program.

- Comments on the Department of Defense's analysis of S.2469, "The International Telecommunications Deregulation Act."

- Comments to the FCC or Common Carrier Docket 81-704, "2° Spacing of Communications Satellites."

MULTIPLE PROBABILITY ASSESSMENTS
BY DEPENDENT EXPERTS

Carson E. Agnew
May 1982

Abstract

When two or more information sources ("experts") provide a decision
maker with information on two or more random variables, the decision maker
using Bayes' rule has an opportunity to (1) update a prior about the random
variables, and (2) calibrate the experts. (Calibration is the process of
adjusting the decision maker's likelihood about the experts' assessments.)
This paper presents a model for this two-way process, and specializes to the
case where the experts' assessment errors have a multivariate normal den-
sity. In general, we find that variables which the decision maker and the
experts regard as independent a priori will be dependent a posteriori
because of dependence in the assessment errors. Formulas for posterior den-
sities are given for the normal model. In this model the posterior density
of the random variables depends on only a weighted average of the expert's
means, with weights that depend on the experts' assessments of previously
known quantities. We also present a special case of the model for which the
mean of the posterior density is correctly given by a simple (unweighted)
average of assessments.

MULTIPLE PROBABILITY ASSESSMENTS
BY DEPENDENT EXPERTS

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Carson E. Agnew

Report No. 36J

November 1981
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Program in Information Policy

Terman Engineering Center
Engineering-Economic Systems Department
Stanford University   Stanford, CA 94305

ABSTRACT

When two or more information sources ("experts") provide a decision

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means, with weights that depend on the experts' assessments of previously

known quantities. We also present a special case of the model for which the

mean of the posterior density is correctly given by a simple (unweighted)

average of assessments.

1.   Introduction

A recent paper by Winkler [5] introduced a consensus model for combining probability assessments from dependent sources of information, which we, like Winkler, will call "experts." Winkler's model is closely related to Morris' [3] Bayesian framework and to the "internal approach" for reconciling probability assessments proposed by Lindley, Tversky and Brown [1]. As with these other models, Winkler's approach requires two probability assessments from the decision maker who is reconciling the experts' distributions. First, the decision maker supplies a prior distribution for the uncertain event. (Since the consensus model deals with random variables, the prior is a density function for a random variable θ.) Second, the decision maker assesses the likelihood of each expert's assessment given the unknown.

Winkler's paper on the consensus model presents the case where a number of experts provide assessments about a single random variable, and both the prior and likelihood are provided by the decision maker.[1] This paper considers the case where the experts provide assessments about several random variables simultaneously. This extension makes it possible to use the experts' assessments both to update the decision maker's prior on the random variables and to calibrate the experts. Calibration, as the term is used here, is the process of adjusting the decision maker's likelihood function for the experts' assessments.

To illustrate how calibration can be accomplished, we use results for the multivariate normal model presented in Section 3.1. There are K experts providing information about M random variables $\theta_1, \ldots, \theta_M$.

We assume that the decision maker regards these variables as independent a
priori (possibly, some of them have been so constructed as to be independ-
ent). The decision maker also believes that the experts' assessments are
unbiased but correlated estimates of these variables, with normally distrib-
uted errors. Consequently, the likelihood function of the assessments is a
multivariate normal density for the assessment errors, with zero mean and a
covariance matrix containing $K(K+1)/2$ parameters. Since there are MK
assessments and $M + K(K+1)/2$ unknowns, if M is large enough it can be
shown that information about the covariance matrix can be extracted from the
experts' assessments, in addition to information about the θ_i's.

Introducing the possibility of joint updating and calibration by using
several assessments per expert is the essence of Morris' calibration proce-
dure [3]. However, Morris deals with the limiting case where the number of
assessments approaches infinity. In the model presented here the number of
assessments need not be infinite before some information can be extracted.

Another consequence of the theory presented below is the following.
Suppose the decision maker believes the random variables being assessed to
be independent a priori. However, after consulting the experts the decision
maker will in general have a posterior density in which the random variables
are dependent. This phenomenon, pointed out in the single-expert case by
Harrison [2], arises because a change in one of the expert's assessments may
affect the posterior distribution of all the θ_i's. Hence the decision
maker learns something about θ_i, say, from an assessment of θ_j
because the assessments are dependent.

The rest of this paper is organized as follows. The next section (§2) introduces Winkler's consensus model and presents the case where the decision maker's prior and likelihood are general density functions. Section 3 then specializes to the normal error model. In addition to illustrating the general points made, this section provides fairly straightforward formulas for the moments of posterior densities. The results in this section, particularly Proposition 3.4, are perhaps the most practically important ones in the paper. Section 4 contains some concluding comments.

2.   The Consensus Model with Multiple Assessments

In the consensus model, generalized to multiple assessments, a vector $\underset{\sim}{\theta} = (\theta_1,\ldots,\theta_M)$ of real-valued, unbounded random variables is of interest to the decision maker.[2] Each of K experts, $i = 1,\ldots,K$, has a probability density $g_i(\underset{\sim}{\theta})$ on these uncertain quantities. The consensus model makes the crucial simplification that the decision maker believes the experts will make only certain kinds of "errors" in assessing these densities. This simplification puts restrictions on the likelihood function that the decision maker must assess, making formulas for calibration easier to implement.

Specifically, the consensus model assumes that experts' assessments differ from $\underset{\sim}{\theta}$ according to an "additive noise" model. Let $\underset{\sim}{\mu}_i$ be a vector of means of the ith expert's probability density on $\underset{\sim}{\theta}$. The assessment error for the ith expert's is defined to be $\underset{\sim}{u}_i = \underset{\sim}{\mu}_i - \underset{\sim}{\theta}$. The decision maker's likelihood function involves only the error vectors.

This assumption that only the errors matter implies that the decision maker thinks that experts' assessments differ by a consistent location shift. Knowledge of $\underset{\sim}{\theta}$ would not change the decision maker's likelihood.[3] However, the likelihood function may incorporate dependence among the experts' errors. In particular, the likelihood function is written $f(\underset{\sim}{u}_1,\ldots,\underset{\sim}{u}_K|\underset{\sim}{\alpha})$, where $\underset{\sim}{\alpha} = (\alpha_1,\ldots,\alpha_P)$ is an additional vector of the parameters in the likelihood function which encode the decision maker's beliefs about the experts.

The parameters $\underset{\sim}{g}$ represent an addition to the consensus model of [5]. They summarize the decision maker's judgement of the accuracy of the experts' probability assessments. In the next section, for example, $\underset{\sim}{g}$ is a matrix of the variances and covariances of the experts' assessment errors. More generally, these parameters could represent biases in assessments, or structural relationships between the errors such as might be produced by a model that the decision maker is consulting.

The decision maker uses the experts' assessments to make inferences about both $\underset{\sim}{\theta}$ and $\underset{\sim}{g}$. He combines a prior $p(\underset{\sim}{\theta}, \underset{\sim}{g})$ with the likelihood function to obtain the posterior density:[4]

$$p(\underset{\sim}{\theta}, \underset{\sim}{g} \mid g_1, \ldots, g_K) \quad \alpha \quad f(\mu_1 - \underset{\sim}{\theta}, \ldots, \mu_K - \underset{\sim}{\theta} \mid \underset{\sim}{g}) p(\underset{\sim}{\theta}, \underset{\sim}{g}) \qquad (2.1)$$

Equation (2.1) is the most general statement of the solution to the problem of multiple assessments. A number of additional assumptions can, if appropriate, simplify the equation and help one to understand its implications. In particular, decision maker may regard $\underset{\sim}{\theta}$ and $\underset{\sim}{g}$ as independent a priori. Such might be the case, for example, if the $\underset{\sim}{\theta}$ represent football point spreads and the $\underset{\sim}{g}$ the reliabilities of bookmakers consulted by the decision maker. Unless the bookmakers can influence the outcomes of the games, $\underset{\sim}{\theta}$ and $\underset{\sim}{g}$ will be independent a priori. (The same remarks apply, of course, to other situations such as the case were $\underset{\sim}{g}$ encodes the reliability of actuaries' assessments of risk or stock market analysts' assessments of earnings per share or the prices of stocks.) However, as can be

seen in this equation, even the a priori independence of $\underset{\sim}{\theta}$ (or $\underset{\sim}{g}$ for

that matter) does not imply a posteriori independence.

Simplifying assumptions also can be made about the decision maker's

likelihood function. Perhaps the two most important ones are when the

decision maker regards the experts' errors u_{ij} to be independent with

respect to one of the two subscripts. If each expert's assessment errors

are independent across the variables being assessed the likelihood function

can be re-written:

$$f(\underset{\sim}{u}_1,\ldots,\underset{\sim}{u}_K|\underset{\sim}{g}) = f(u_{11},u_{12},\ldots,u_{1M},u_{21},\ldots,u_{KM}|\underset{\sim}{g})$$

$$= \prod_{j=1}^{M} f_j(u_{1j},u_{2j},\ldots,u_{Kj}|\underset{\sim}{g})$$

$$= \prod_{j=1}^{M} f_j(\underset{\sim}{u}_{(j)}|\underset{\sim}{g}) \qquad\qquad (2.2)$$

where $\underset{\sim}{u}_{(j)} = (u_{1j},\ldots,u_{Kj})$. In this case the decision maker regards the

experts as dependent, due for instance to their common knowledge of public

information. However, the dependence has the same probabilistic form for

each θ_i, $i = 1,\ldots,M$.

The assumption of independence among the θ_i may seem unlikely in

realistic situations. However, one may be able to arrange for it to hold by

asking the experts for additional assessments of variables which the deci-

sion maker selects to be independent a priori. The assessments of these

variables are used to calibrate the experts. Such a procedure is used in

Morris' calibration procedure, and in what Lindley, Tversky and Brown call "extending the conversation" with the expert.[5]

In some cases the additional assessments may not be of intrinsic interest to the decision maker. Alternatively, the assessments themselves may be of interest, but have been selected by the decision maker to give the independence property. For example, the decision maker may regard the price of a security in successive periods as dependent, but the successive first differences of prices may be variables which are considered independent.

The other important case arises when the ith expert's errors for θ_j and θ_k are dependent, but the ith and l^{th} experts themselves are independent. In this case the likelihood function is:

$$f(\underset{\sim}{u}_1, \ldots, \underset{\sim}{u}_K | \underset{\sim}{x}) = \prod_{i=1}^{K} f_i(\underset{\sim}{u}_i | \underset{\sim}{x}) \tag{2.3}$$

This case was not considered by Winkler, but could arise in several situations. One of these occurs if the experts possess a great deal of independent, private information about $\underset{\sim}{\theta}$. For example, geologists working for a petroleum exploration company may be asked to assess the values of adjacent tracts for the purposes of bidding for a lease. Each geologist will have some common information available, of course. But, there may also be proprietary data which is so much more detailed that the decision maker believes it dominates the public information. On the other hand, because the tracts are adjacent (and hence likely to share common geologic structures), the values of tracts j and k may be correlated.

Another situation where this assumption may be justified is when the decision maker believes that certain experts tend to be optimistic or pessimistic in their assessments. Thus, a knowledge of u_{ij} (say) would lead the decision maker to revise his density on u_{ik}, but not on $u_{\ell i}$ or $u_{\ell k}$. The commonplace identification of some securities analysts as "bullish" or "bearish" is an example of this case, since the degree of optimism or pessimism is associated with the individual expert rather than the variables being assessed.

3.   A Model with Normally Distributed Errors

This section specializes the model of the preceding section to the case where the experts' errors are normally distributed. In this case the parameters $\underset{\sim}{\alpha}$ are elements of covariance matrices of appropriate dimension. To save space, and because most of the derivations are based on standard sources, (e.g., Press [4] or Zellner [6]), the main results are presented as propositions. Some details are provided in an Appendix to this paper. Also, because the details can be found in the sources just cited and add little to the interpretation of our results, we will consider only the case where the decision maker has a diffuse prior on the variables $\underset{\sim}{\theta}$.

In order to deal easily with the two special cases introduced in the last section it will be helpful to introduce some additional notation. Thus, we let $\underset{\sim}{U}$ be the $M \times K$ matrix of errors, with:

$$\underset{\sim}{U} = \left[u_{ij} \right] = \begin{bmatrix} \underset{\sim}{u}'_{(1)} \\ \vdots \\ \underset{\sim}{u}'_{(M)} \end{bmatrix} = \left[\underset{\sim}{u}_1, \ldots, \underset{\sim}{u}_K \right]$$

Similarly the matrix of the experts' assessments is:

$$\underset{\sim}{M} = \left[\mu_{ij} \right] = \begin{bmatrix} \underset{\sim}{\mu}'_{(1)} \\ \vdots \\ \underset{\sim}{\mu}'_{(M)} \end{bmatrix} = \left[\underset{\sim}{\mu}_1, \ldots, \underset{\sim}{\mu}_K \right]$$

We will also wish to write the errors and assessments as   (KM × 1)

vectors. Thus, we define:

$$\underset{\sim}{u}. = \begin{bmatrix} \underset{\sim}{u}_1 \\ \vdots \\ \underset{\sim}{u}_K \end{bmatrix}$$

and

$$\underset{\sim}{\mu}. = \begin{bmatrix} \underset{\sim}{\mu}_1 \\ \vdots \\ \underset{\sim}{\mu}_K \end{bmatrix}$$

3.1 Dependent experts, independent random variables

We will first consider the case where experts' errors are dependent,

but the decision maker believes that the experts' assessments are independ-

ently and identically normally distributed across variables.

Letting $\underset{\sim}{\Sigma}_K$ be the K × K covariance matrix of the experts' errors,

the likelihood function for this case is:

$$f(\underset{\sim}{u} | \Sigma_K^{-1}) = f(\underset{\sim}{M} | \underset{\sim}{\theta}, \Sigma_K^{-1})$$

$$\alpha \; |\Sigma_K^{-1}|^{M/2} \exp\left[-(1/2) \sum_{j=1}^{M} \underset{\sim}{u}'_{(j)} \; \Sigma_K^{-1} \; \underset{\sim}{u}_{(j)}\right] \qquad (3.1)$$

This likelihood function can be rewritten in terms of a $K \times K$ "sum of squares" matrix $\underset{\sim}{S}(\theta)$:

$$f(\underset{\sim}{M}|\theta, \Sigma_K^{-1}) \; \alpha \; \left| \Sigma_K^{-1} \right|^{M/2} \exp\left[-(1/2) \; \mathrm{tr} \; \underset{\sim}{S}(\theta) \; \Sigma_K^{-1}\right] \tag{3.2}$$

where:

$$\underset{\sim}{S}(\theta) = \sum_{j=1}^{M} \underset{\sim}{u}_{(j)} \; \underset{\sim}{u}'_{(j)}$$

$$= (\underset{\sim}{M} - \underset{\sim}{\theta} \; \underset{\sim}{e}'_K)'(\underset{\sim}{M} - \underset{\sim}{\theta} \; \underset{\sim}{e}'_K) \tag{3.3}$$

and $\underset{\sim}{e}_K$ is a $K \times 1$ vector of ones.

In this case we will use a Wishart conjugate prior density on Σ_K^{-1}:

$$p(\Sigma_K^{-1}|\nu, \underset{\sim}{S}_0) \; \alpha \; \left| \Sigma_K^{-1} \right|^{(\nu-K-1)/2} \exp\left[-(1/2) \; \mathrm{tr}(\nu \underset{\sim}{S}_0 \Sigma_K^{-1})\right] \tag{3.4}$$

where $\underset{\sim}{S}_0$ is a positive definite $K \times K$ matrix and $\nu > 0$ is a "degrees of freedom" parameter. The case $\nu = 0$ represents an improper diffuse prior on Σ_K^{-1}.

Combining the likelihood and the prior gives the following posterior density on $\underset{\sim}{\theta}$ and Σ_K^{-1}:

$$p(\underset{\sim}{\theta}, \Sigma_K^{-1}|\underset{\sim}{M}, \nu, \underset{\sim}{S}_0) \; \alpha \; \left| \Sigma_K^{-1} \right|^{(M+\nu-K-1)/2} \exp\{-(1/2) \; \mathrm{tr}\left[\nu \underset{\sim}{S}_0 + \underset{\sim}{S}(\theta)\right] \Sigma_K^{-1}\} \tag{3.5}$$

This density is a non-central Wishart distribution function. Viewed as a joint density its properties are very complicated, although some analytic results are known (e.g., [4]). Fortunately, we can often work with marginal or conditional densities, as summarized in the following propositions.

To make the following propositions more tangible, consider the simple example whose data are given in Table 1. A decision maker is interested in two variables S and ε, and consults two experts, A and B. Initially the decision maker considers the experts to be independent, and assesses a prior with $\nu = 2$, and $S_0 = I_2$, a two-by-two identity matrix. When the decision maker consults the experts he or she supplements the conditional means for the two variables of interest with values for three other variables, α, β and γ, whose correct values are known to the decision maker.

Proposition 3.1: Given θ, the posterior density on Σ_K^{-1} is a Wishart density of the form given in Equation (3.5), with $M + \nu$ "degrees of freedom," and weighting matrix $\nu S_0 + S(\theta)$. The density is proper only if $M + \nu > K$ and the matrix $\nu S_0 + S(\theta)$ is positive definite ([4], p. 101). The posterior mean precision matrix is:

$$E(\Sigma_K^{-1} | M, \nu, S_0) = (M + \nu)\left[\nu S_0 + S(\theta)\right]^{-1} \qquad (3.6)$$

This proposition is the basic result for pure calibration of the experts. It says that if we are able to compare the experts' assessments with the true values of θ, the posterior mean precision is a weighted sum precision S_0 (if any) and the cross product matrix $S(\theta)$ evaluated at the of prior true values of θ.

If $\sum_{k}^{-1}$ has the Wishart density in Equation (3.5) it can be shown that $\sum_{k}$ has an inverted Wishart density with $M + v + K + 1$ "degrees of "freedom." The properties of this density are summarized in [4] and [6]. If $M + v > K + 1$ the mean of this density exists and is given by:

$$E(\sum_{k}|M,v,S_o) = [v\,S_o + S(\theta)]/(M + v - K - 1) \qquad (3.7)$$

In terms of the example introduced above, we have $M = 3$ and the matrix $v\,S_o + S(\theta)$ is:

$$v\,S_o + S(\theta) = 2\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} 1.70 & 1.90 \\ 1.90 & 2.54 \end{bmatrix}$$

Hence the mean posterior covariance matrix is:

$$E(\sum_2|M,v,S_o) = \begin{bmatrix} 1.85 & 0.95 \\ 0.95 & 2.27 \end{bmatrix}$$

The posterior correlation derived from this matrix is 0.46, suggesting that the experts are dependent.

Proposition 3.2: If $\sum_K^{-1}$ is known[6] the conditional density on θ is a multivariate normal with mean θ^* and covariance matrix $\sigma^{*2}I_M$ where:

$$\theta^* = (M\,\sum_K^{-1}\,e_K)/(e_K'\,\sum_K^{-1}\,e_K) \qquad (3.8)$$

$$\sigma^{*2} = 1/(e_K'\,\sum_K^{-1}\,e_K) \qquad (3.9)$$

This proposition is a restatement of Winkler's analysis [5] when $\underset{\sim}{\theta}$ is a vector. The posterior mean $\underset{\sim}{\theta}*$ is a weighted sum of the experts' assessments, with the weights determined by the precision matrix $\underset{\sim}{\Sigma}_K^{-1}$. Also, the elements of $\underset{\sim}{\theta}$ are mutually independent $\underline{\text{a posteriori}}$. This illustrates that the dependence among the $\underset{\sim}{\theta}$ arises solely from the dependence among the experts, a point confirmed in the next proposition.

In the example we have been following, the data were actually generated from a bivariate normal density function with both variances equal to 1.0 and a correlation coefficient of 0.7 (before rounding off). In this case it is easily shown tht the optimal weights are $\underset{\sim}{\theta}* = (0.5,0.5)'$, and that $\sigma* = 0.922$. Hence the posterior means of δ and ϵ given knowledge of $\underset{\sim}{\Sigma}_k^{-1}$, i.e., complete calibration, would be 7.75 ± 0.92 and 8.65 ± 0.92. In fact, the data were generated so that the true means where 7.0 and 9.0.

<u>Proposition 3.3</u>: The posterior marginal density on $\underset{\sim}{\theta}$ is a matrix-t density function:

$$p(\underset{\sim}{\theta}|\underset{\sim}{M},\nu,\underset{\sim}{S}_0) \quad \alpha \quad \left|1 + (\underset{\sim}{\theta} - \underset{\sim}{\theta}_o)'\underset{\sim}{A}_o^{-1}(\underset{\sim}{\theta} - \underset{\sim}{\theta}_o)\right|^{(M+\nu)/2} \qquad (3.10)$$

where:

$$\underset{\sim}{\theta}_o = \underset{\sim}{M}\,\underset{\sim}{S}_o^{-1}\,\underset{\sim}{e}_K/(\underset{\sim}{e}_K'\,\underset{\sim}{S}_o^{-1}\,\underset{\sim}{e}_K) \qquad (3.11)$$

$$\sigma_o^2 = \nu/\underset{\sim}{e}_K'\,\underset{\sim}{S}_o^{-1}\,\underset{\sim}{e}_K \qquad (3.12)$$

$$\underset{\sim}{A}_o = \sigma_o^2[\underset{\sim}{I}_M + (\underset{\sim}{M} - \underset{\sim}{\theta}_o\,\underset{\sim}{e}_K')(\nu\,\underset{\sim}{S}_o)^{-1}(\underset{\sim}{M} - \underset{\sim}{\theta}_o\,\underset{\sim}{e}_K')'] \qquad (3.13)$$

In order for Equation (3.10) to be a proper density function we must have $\nu > 0$. If $\nu > 1$ the posterior mean of $\underset{\sim}{\theta}$ is $\underset{\sim}{\theta}_0$, and if $\nu > 2$ the covariance matrix of $\underset{\sim}{\theta}$ is $\underset{\sim}{A}_0/(\nu-2)$.

This proposition considers the case where $\underset{\sim K}{\Sigma}^{-1}$ is unknown. The posterior mode $\underset{\sim}{\theta}_0$ of $\underset{\sim}{\theta}$ is calculated using the same weighted-sum formula as when $\underset{\sim K}{\Sigma}^{-1}$ is known, except that the prior "sum of squares" matrix $\nu \underset{\sim}{S}_0$ provides the weights instead of $\underset{\sim}{S}(\underset{\sim}{\theta})$. However, the covariance matrix of the $\underset{\sim}{\theta}$ (proportional to $\underset{\sim}{A}_0$) is no longer diagonal; in addition to the term $\sigma_0^2 \underset{\sim}{I}_M$ there is a term involving the deviations of the assessments from $\underset{\sim}{\theta}_0$.

Notice also in this case that the decision maker <u>must</u> provide some prior information (i.e., $\nu > 0$) if the posterior density is to integrate to one. The posterior thus represents a real mixture of the experts' assessments with the decision maker's beliefs about the experts assessment abilities.

In the example here, only the decision maker's prior information would be used, i.e., $\nu = 2$ and $\underset{\sim}{S}_0 = \underset{\sim}{I}_2$. In this case the weights are again equal, and $\sigma_0 = 1.0$. However, the number of "degrees of freedom" are one too few for the second moments of the posterior on δ and ϵ to exist. If this were not so, the $\underset{\sim}{A}_0$ matrix would show a slight degree of correlation between the variables.

Propositions 3.1 and 3.3 can be used to derive the predictive density for a new set of variables (say an $M_2 \times 1$ vector $\underset{\sim}{\theta}_2$) given a new set of assessments (say a matrix $\underset{\sim}{M}_2$), and the results of a prior calibration step in which both the assessment matrix $\underset{\sim}{M}$ and the "true" values of $\underset{\sim}{\theta}$ were obtained. By Proposition 3.1 the precision matrix $\underset{\sim K}{\Sigma}^{-1}$ has a Wishart density with $M + \nu$ degrees of freedom and weighting matrix $\nu \underset{\sim}{S}_0 + S(\underset{\sim}{\theta})$.

To find the predictive density of θ_2 given M_2 , M and θ we replace θ by θ , M by M_2, and so on. The case where the original prior is diffuse ($\nu = 0$) and $M_2 = 1$ will give the "data based" prior used in the football point spread example in [5]. In the general case $\nu \geq 0$ we have:

Proposition 3.4: When $S(\theta)$ is known from a previous calibration step, the predictive density for the new assessments is given by Equations (3.13)-(3.16):

$$p(\theta_2|M_2,S(\theta),\nu,S_o) \quad \alpha \quad \left| 1 + (\theta_2-\theta_{20})'A_2^{-1}(\theta_2-\theta_{20}) \right|^{-(M+M_2+\nu)/2} \quad (3.14)$$

there

$$\theta_{20} = \{M_2[\nu S_0 + S(\theta)]^{-1}e_K\}/[e_K'[\nu S_0 + S(\theta)]^{-1}e_K] \quad (3.15)$$

$$s^2 = 1/\{e_K'[\nu S_0 + S(\theta)]^{-1}e_K\} \quad (3.16)$$

$$A_2 = s^2\{I_2 + (M_2 - \theta_{20}e_K')[\nu S_0 + S(\theta)]^{-1}(M_2 - \theta_{20}e_K')'\} \quad (3.17)$$

In the example, this proposition tells us how to combine the decision maker's prior with the extra assessments made by the experts. Calculation shows that the weights the decision maker uses on the experts' assessments of the mean are now $(0.595, 0.405)'$, so that slightly more weight is given to Expert A than to Expert B. This occurs because Expert A's assessments of α, β and γ happened to be closer to the actual values than Expert B's assessments. (Given the way the data were generated, it is evident that if there were many more questions the weights would gradually swing back towrds

equality, which is optimal if $\sum_k^{-1}$ is known.) The posterior density on δ

and ϵ is a matrix-t density whose mean vector is (7.68, 8.66) and covari-

ance matrix:

$$A_2/(m + \nu - 2) = \begin{bmatrix} 1.10 & -0.0156 \\ -0.0156 & 0.992 \end{bmatrix}$$

The implied correlation coefficient is about 0.01, so that in this cae at

least the dependence of the experts has not made much difference in the

decision maker's posterior density.

Table 2 shows the relevant statistics for the three cases discussed

above. The fourth case shown is what would have happened with a diffuse

prior on $\sum_k^{-1}$, i.e., if $\nu = 0$. Ironically, in this case the posterior

means are actually closer to the actual values in this case than in any

other, despite the fact that the weights used in this case are far from

correct, namely (1.45, -0.45).

3.2 Independence among the experts but dependence

among the random variables

We turn now to the second special case introduced in Section 2, where

the decision maker believes that the experts' assessments on any particular

variable are independent, but that the assessments will be dependent when

considered across the variables being assessed. Moreover, the decision

maker views the experts as making identically distributed errors.[7]

In this case the error vectors u_i and u_j are independent and

identically normally distributed, with zero mean and $M \times M$ positive

definite covariance matrix Σ_M. Hence the likelihood function can be written:

$$f(M|\theta,\Sigma_M^{-1}) \; \alpha \; |\Sigma_M^{-1}|^{K/2}\exp\left[-(1/2)\sum_{i=1}^{K}(\mu_i - \theta)'\Sigma_M^{-1}(\mu_i - \theta)\right]$$

$$\alpha \; |\Sigma_M^{-1}|^{K/2}\exp\{-(1/2)tr[V + K(\theta - \overline{\theta})(\theta - \overline{\theta})']\Sigma_M^{-1}\} \quad (3.18)$$

where

$$\overline{\theta} = \frac{1}{K}\sum_{i=1}^{K}\mu_i \qquad\qquad (3.19)$$

$$V = \sum_{i=1}^{K}(\mu_i - \overline{\theta})(\mu_i - \overline{\theta}) \qquad\qquad (3.20)$$

Thus $\overline{\theta}$ is the simple average of the experts' assessments, and V is the associated $M \times M$ cross-product matrix.

As in the preceding subsection we assume a diffuse prior on θ and a Wishart prior on the precision matrix Σ_M^{-1}. Specifically:

$$p(\theta,\Sigma_M^{-1}) \; \alpha \; |\Sigma_M^{-1}|^{(\nu-M-1)/2}\exp\left[-(1/2) \; tr(\nu \, V_0 \, \Sigma_M^{-1})\right] \quad (3.21)$$

where V_0 is a positive definite $M \times M$ matrix and $\nu \geq 0$. The resulting posterior density is:

$$p(\theta,\Sigma_M^{-1}|M,\nu,V_0) \; \alpha \; |\Sigma_M^{-1}|^{(K+\nu-M-1)/2}$$

$$\times \exp\{-(1/2) \; tr[\nu \, V_0 + V + K(\overline{\theta}-\theta)(\overline{\theta}-\theta)']\Sigma_M^{-1} \quad (3.22)$$

This posterior density leads immediately to the following propositions:

Proposition 3.5: The marginal posterior density on Σ_M^{-1} is a Wishart

density with $K + \nu$ "degrees of freedom" and weighting matrix

$\nu V_0 + V$. Hence the conditional mean precision is:

$$E(\Sigma_M^{-1} | M, \nu, V_0) = (K + \nu)(\nu V_0 + V)^{-1} \qquad (3.23)$$

In this case the unknowns θ do not have to be revealed to obtain the

density of Σ_M^{-1} in a useful form. However, it should be noted that the

density of the precision matrix does not condense as the number of

assessments M increases, when the number of experts K is held fixed.

Intuitively, this is because increasing the number of variables also

increases the number of unknowns.

Proposition 3.6: The posterior marginal density of θ is a matrix-t

density function:

$$p(\theta | M, \nu, V_0) \quad \alpha \quad \left| 1 + (\theta - \bar{\theta})' B^{-1}(\theta - \bar{\theta}) \right|^{-(K+\nu)/2} \qquad (3.24)$$

where $B = (\nu V_0 + V)/K$. This density is proper provided $K + \nu > M$,

and has mean $\bar{\theta}$ provided $K + \nu > M + 1$. If $K + \nu > M + 2$ the

covariance of θ is $(K + \nu)B/(K + \nu - M - 2)$.

This proposition says that when the experts' assessments are regarded

as independent the posterior mean of θ is a simple average of the

assessments--no weighting by covariance matrices is needed. The elements of $\underset{\sim}{\theta}$ are dependent $\underline{a}$ $\underline{posteriori}$ because the variables themselves are dependent, with covariance matrix proportional to $\nu \underset{\sim}{V_0} + \underset{\sim}{V}$.

The appearance of a $\overline{\underset{\sim}{\theta}}$ is interesting because so many informal techniques for achieving a "consensus" of experts' forecasts use a simple average. If we are willing to accept the posterior mean (or mode) of the density in Equation (3.22) as an estimator, the above model gives a case where the simple averaging of assessments is the correct way to proceed. Informally, the proposition says if the experts' private information dominates the public information, no attempt should be made to weight the assessments for "reliability."

3.3   The Case of General Dependence

In the general case, the error vector $\underset{\sim}{u}_{\bullet}$ has a multivariate normal distribution with mean $\underset{\sim}{X} \underset{\sim}{\xi}$ and positive definite covariance matrix $\underset{\sim}{\Omega}$, where $\underset{\sim}{X}$ is an $MK \times M$ matrix of ones and zeros. Since we assume that each expert assesses all the random variables we can write $\underset{\sim}{X}$ in a particularly simple form:

$$\underset{\sim}{X} = \underset{\sim}{I_M} \otimes \underset{\sim}{e_K} \tag{3.25}$$

where $\underset{\sim}{I_M}$ is a $M \times M$ identity matrix and $\underset{\sim}{e_K}$ is an $K \times 1$ vector of ones. ($\otimes$ denotes the direct or Kroneker product of two matrices.) The

likelihood function in this case is:

$$f(\underline{\mu}_. | \underline{\theta}, \underline{\Omega}, \underline{X}) \quad \alpha |\underline{\Omega}|^{-1/2} \exp[- (1/2)(\underline{\mu}_. - \underline{X} \underline{\theta})' \underline{\Omega}^{-1}(\underline{\mu}_. - \underline{X} \underline{\theta})] \quad (3.26)$$

Since there are MK assessments provided by the experts, and the likelihood function contains $M + MK(MK + 1)/2$ parameters, the posterior density function on $\underline{\theta}$ and $\underline{\Omega}$ cannot be expected to be a proper density unless some additional information, either in the form of a prior density on $\underline{\theta}$ and $\underline{\Omega}$, or in the form of restrictions applied to some of the parameters, is supplied. If prior information is supplied we are dealing with a case like Winkler's. For example, suppose the decision maker can supply the matrix $\underline{\Omega}$. In this case the conditional density of $\underline{\theta}$ given $\underline{\Omega}$ is the product of the likelihood function given above and the prior density on $\underline{\theta}$. The treatment is essentially the same as in Proposition 3.2, except that the conditional mean is $\underline{\theta}^* = (\underline{X}' \underline{\Omega}^{-1}\underline{X})^{-1} \underline{X}'\underline{\Omega}^{-1}\underline{\mu}_.$, with covariance matrix $(\underline{X}'\underline{\Omega}^{-1}\underline{X})^{-1}$.

The other alternative is to place restrictions on parameters. The possibilities here are almost limitless. Indeed the special cases considered in the preceding two sections are equivalent to requiring $\underline{\Omega} = \underline{I}_M \otimes \underline{\Sigma}_K$ and $\underline{\Omega} = \underline{\Sigma}_M \otimes \underline{I}_K$, respectively. Other possibilities include making $\underline{\Omega}$, $\underline{\Sigma}_K$ or $\underline{\Sigma}_M$ functions of a smaller number of parameters. (Winkler's equicorrelated case is an example of this.) The particular choices will undoubtedly depend on the decision maker's particular assessment problem, and we will not work out the details of any particular special case here.

4.   Concluding Remarks

This paper assumes that all K experts assess the M unknown varia-
bles. However, there are many practical circumstances where this will not
be the case. Either some assessments will be unavailable by chance, or the
decision maker will consciously restrict their number in order to reduce the
assessment burden placed on the experts. Indeed, the introduction of multi-
ple assessments introduces an experimental design issue not present when
there is only one unknown. Although the details are beyond the scope of
this paper it should be clear that various sorts of block design, entirely
analogous to those studied in classical statistics, can be used to reduce
the experts' workload.

Another point to be made about the procedure discussed in this paper is
that an expert need not be human to provide an assessment. A model, or even
actual data will do just as well. For example, one could use the price of a
security in a previous period to predict a future price. Indeed, one could
mix the assessments of models with judgmental forecasts in a straightforward
manner.

Finally, the model discussed here opens several areas for further
work. The first of these is the detailed investigation of the incomplete
experimental designs discussed above. A second area of interest would be to
allow the experts' errors to have non-zero means (i.e., to be consistently
"biased" in one direction or another). For the normal model, the addition
of bias leads us from a model resembling a one-way analysis of variance to
one that resembles a two-way analysis of variance. (However, the conven-
tional analysis of variance model does not assume general covariance
matrices.)

A third area which has not been fully explored here is the relationship between the calibration results, particularly for the normal model, and the use of exchangeability by Morris to calibrate experts. There are two related issues here. First, if the decision maker considers the $\underset{\sim}{\theta}$ to be exchangeable, but not independent, how can general dependence among the experts be handled? Second, what is the consequence of assuming that the experts' errors are exchangeable, instead of being dependent in a general way? Specifically, does such an assumption help to simplify the calculations of posterior densities when either K or M or both are large?[8]

APPENDIX

This appendix contains some details of the derivation of the propositions presented in Section 3. We begin by deriving Equation (3.2) from Equation (3.1):

$$\sum_{j=1}^{M} u'_{(j)} \Sigma_K^{-1} u_{(j)} = \mathrm{tr}\{[\sum_{j=1}^{M} u_{(j)} u'_{(j)}] \Sigma_K^{-1}\}$$

$$= \mathrm{tr}\{[\sum_{j=1}^{M} (\mu_{(j)} - \theta_j e_K)(\mu_{(j)} - \theta_j e_K)'] \Sigma_K^{-1}\}$$

$$= \mathrm{tr}\ (M - \theta\, e'_K)'(M - \theta\, e'_K)\ \Sigma_K^{-1}$$

$$= \mathrm{tr}\ S(\theta)\ \Sigma_K^{-1}$$

where the next-to-last line follows from the fact that the (i,k) element of the matrix in brackets is $\sum_{j=1}^{M} u_{ji} u_{jk} = u'_i\, u_k$. Hence the sum of squares matrix $S(\theta) = U'U = (M - \theta\, e'_K)'(M - \theta\, e'_K)$. _Proposition 3.1_ is immediate from this calculation and the assumed form of the prior density.

To obtain _Proposition 3.2_ we use:

$$\mathrm{tr}\ S(\theta)\ \Sigma_K^{-1} = \mathrm{tr}(M - \theta\, e'_K)\ \Sigma_K^{-1}(M - \theta\, e'_K)'$$

$$= \mathrm{tr}[(M - \theta^* e'_K)\ \Sigma_K^{-1}(M - \theta^* e'_K)' + (\theta - \theta^*)(\theta - \theta^*)'/\sigma^{*2}]$$

since $(M - \theta^* e'_K)\ \Sigma_K^{-1} e_K(\theta - \theta^*) = 0(\theta - \theta^*) = 0$, where θ^* and σ^* are defined in Equations (3.8) and (3.9). Only the second term involves θ, and this is clearly the exponent of an independent normal density.

Proposition 3.3 is obtained by almost similar steps, except that the posterior density involves $\text{tr} \, [v\underset{\sim}{S}_0 + \underset{\sim}{S}(\underset{\sim}{\theta})] \, \underset{\sim}{\Sigma}_K^{-1}$, so that integrating out the precision matrix $\underset{\sim}{\Sigma}_K^{-1}$ as described in Press [4] or Zellner [6] gives:

$$p(\underset{\sim}{\theta}|\underset{\sim}{M}, v, \underset{\sim}{S}_0) \quad \alpha \quad \left| v\underset{\sim}{S}_0 + \underset{\sim}{S}(\underset{\sim}{\theta}) \right|^{-(v+M)/2}$$

$$\alpha \quad \left| v\underset{\sim}{S}_0 + (\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K')'(\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K') \right|^{-(v+M)/2}$$

$$\alpha \quad \left| \underset{\sim}{I}_K + (\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K')'(\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K')(v\underset{\sim}{S}_0)^{-1} \right|^{-(v+M)/2}$$

$$\alpha \quad \left| \underset{\sim}{I}_M + (\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K')(v\underset{\sim}{S}_0)^{-1}(\underset{\sim}{M} - \underset{\sim}{\theta}\underset{\sim}{e}_K')' \right|^{-(v+M)/2}$$

$$\alpha \quad \left| \underset{\sim}{I}_M + (\underset{\sim}{M} - \underset{\sim}{\theta}_0\underset{\sim}{e}_K')(v\underset{\sim}{S}_0)^{-1}(\underset{\sim}{M} - \underset{\sim}{\theta}_0\underset{\sim}{e}_K')' \right.$$
$$\left. + (\underset{\sim}{\theta} - \underset{\sim}{\theta}_0)(\underset{\sim}{\theta} - \underset{\sim}{\theta}_0)'/\sigma_0^2 \right|^{-(v+M)/2}$$

$$\alpha \quad \left| \underset{\sim}{A}_0 + (\underset{\sim}{\theta} - \underset{\sim}{\theta}_0)(\underset{\sim}{\theta} - \underset{\sim}{\theta}_0)' \right|^{-(v+M)/2}$$

$$\alpha \quad \left| 1 + (\underset{\sim}{\theta} - \underset{\sim}{\theta}_0)'\underset{\sim}{A}_0^{-1}(\underset{\sim}{\theta} - \underset{\sim}{\theta}_0) \right|^{-(v+M)/2}$$

where $\underset{\sim}{\theta}_0$, σ_0 and $\underset{\sim}{A}_0$ are defined in Equations (3.11)-(3.13).

Proposition 3.4 is merely a restatement of Proposition 3.3, using the fact established in Proposition 3.1 that the conditional posterior density of $\underset{\sim}{\Sigma}_K^{-1}$ given $\underset{\sim}{\theta}$ is of the Wishart form.

Finally, Propositions 3.5 and 3.6 are simply special cases of the general multivariate model, and the derivations can be found in Press [4], Chapter 7.

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Footnotes

[1] Winkler provides an example in which the likelihood function is "data based," i.e., is estimated from past observations. This paper shows how this approach is related to a calibration of experts using past data.

[2] All vectors are column vectors. A prime superscript indicates a transpose.

[3] Winkler's paper [5] discusses this assumption in more detail, and also suggests ways to rescale random variables so that the transformed variables satisfy the assumption, even when the untransformed variables do not.

[4] Notice that $f(\mu_1 - \theta, \ldots, \mu_K - \theta | \alpha)$ is the conditional density of $\mu_1, \ldots, \mu_K$ given θ and α.

[5] However, Morris' procedure requires only exchangeability among the events assessed.

[6] Since we assume Σ_K^{-1} to be known, the prior on Σ_K^{-1} is superfluous. This proposition is thus based only on the likelihood function, Equation (3.2).

[7] The latter assumption is admittedly restrictive. It can probably be justified as an approximation whenever the number of experts K becomes moderately large. Otherwise each expert would have a covariance matrix (say Σ_M^i for $i = 1, \ldots, K$), and the decision maker would have to provide K prior densities.

Table 1 — Experts' Assessments and Known
Values for Example

Variable	Expert A's Mean	Expert B's Mean	Known Value
α	0.9	0.3	1.0
β	4.2	4.4	3.0
γ	4.5	4.7	5.0
δ	7.4	8.1	?
ϵ	8.7	8.6	?

Table 2 — Moments of Decision Makers' Posterior
Density on δ and ϵ

	Variable δ	Variable ϵ
Based on perfect information about $\Sigma_{a_k}^{-1}$ (Proposition 3.2)	7.75 (0.92)	8.65 (0.92)
Based on prior only (Proposition 3.3)	7.75 (*)	8.65 (*)
Based on prior and assessments of α, β and γ (Proposition 3.4)	7.68 (1.05)	8.66 (1.00)
Based on assessments of α, β and γ only	7.08 (1.83)	8.75 (1.28)
Correct value	7.0	9.0

Figures in parentheses are standard errors. * means that the moment does not exist.

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UNDERSTANDING THE LANDSAT MARKET
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Abstract

The National Oceanic and Atmospheric Administration (NOAA) recently headed an interagency task force to determine the technical parameters and institutional arrangements for a U.S. operational earth resource sensing system. One of the most important and least understood inputs confronting the task force was the market for Landsat products and ground processing equipment. While the U.S. government represents somewhat over half of the 1979 market (about 52%), the foreign segment of the market is substantial (about 36%), and is expected to grow rapidly.* In particular, the developing nations of the world represent a large potential market for Landsat data and products. This paper is an effort to understand the Landsat market in developing countries, and the constraints on the growth of that market which stem from the development process itself and from a country's technical, political and institutional attributes.

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* Private Sector Involvement in Civil Space Remote Sensing, NASA Headquarters, June, 1979, see also Planning for a Civil Operational Land Remote Sensing Satellite System: A Discussion of Issues and Options, NOAA Headquarters, June 1980.

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PROGRAM IN INFORMATION POLICY

Engineering-Economic Systems Department
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CONTENTS

1. OVERVIEW

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2. INTRODUCTION

Four competing factors guide the development of policy regarding an operational land remote sensing system, and it is important to outline them at the outset, for they provide the broad societal context for the analysis in this paper: 1) there is a need to boost U.S. exports in areas where the U.S. holds a technological lead; 2) the need to develop user applications in developing countries on their terms coincides with a foreign policy imperative to maintain good relations with third world nations; 3) developing countries desire to take control of their own development and the types of technology and indu; : which they adopt;[2] and 4) the U.S. government wants to enlist the participation of major companies in the management, operation ard ownership of the operational system. Such participation requires a substantial world-wide market. A more in-depth look at these four factors follows.

First, declining U S. productivity and the decline of U.S. technological superiority in many international markets impels the U.S. to take advantage of any technological lead which it holds. There is, as well, an economic imperative

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[2] Lately there has been a shift in rhetoric from an emphasis on GNP growth and the "trickle down" theory of development to the meeting of basic human needs. While this is of course not universally true, the principle of the theoretic shift has been accepted by the World Bank and other international institutions. See Baum, Warren, "The World Bank Project Cycle", in Finance and Development, 12/78.

in capitalist systems which calls for exploitation of a technological monopoly when it exists. Earth resource sensing satellites represent an area where the U.S. holds an edge over its nearest competitors. The French and the Japanese will not be launching experimental systems until the mid-1980's.[3] By that time the U.S. should have an interim-operational system based on the Landsat D spacecraft and sensor system in the air.[4] However, recent Congressional testimony suggests that foreign systems may, by leapfrogging primitive U.S. systems, catch up to or move ahead of U.S. systems technologically.[5] Foreign countries also may be tailoring their systems to the needs of the developing countries, thereby, cutting into the U.S. market share. Hence, one factor guiding U.S decision-makers is that of supporting U.S. industry in a highly competitive world.

Second, in contrast to the strictly domestic economic needs of the country, the health of the international economic community demands the development of third world countries in an effort to stabilize a seemingly chaotic world situation. The recent Afghanistan crisis should not blind us to

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[3] PSIS and Issues and Options op. cit.

[4] Ibid.

[5] See Statement by Mr. David Johnson, Director National Environmental Satellite Service, National Oceanographic and Atmospheric Administration, Department of Commerce, Before the Committee on Communication, Science and Transportation, Subcommittee on Science, Technology and Space, June 26, 1980.

the fact that the East-West cleavage in international rela-
tions has been fading in place of a growing north-south con-
flict over the call for a new international economic order.
Even in the context of a renewed cold war, the U.S. will no
longer be able to ignore the demands of the developing world
if it hopes to maintain a viable foreign policy.

Third, there is a growing demand by third world nations to
control their own development. As such, the profit motives
of U.S. companies may run headlong into a host country's
desire to develop its resources and population in a stable
manner. For instance, even if Landsat data is the most
cost-effective and most efficient way to obtain resource
information, and we in the developed world would immediately
adopt it it may not make any sense for a developing country
with a huge labor surplus that could employ many people
doing ground surveys. If the U.S. wants to develop markets
in third world nations, it may have to do so on terms set to
some extent by those nations.

Fourth, the National Aeronautics and Space Administration is
in the process of transferring the operational earth
resources sensing program to the Department of Commerce's
National Oceanic and Atmospheric Administration (NOAA). As
a part of that transfer NOAA must initiate private sector
involvement, and deal with international participation.

Work done thus far[6] on private sector and foreign involvement has focused on efforts to determine how to entice companies into owning and operating the operational system. Following the example of the communications satellite industry, one might conjecture, the government would continue to pursue long-term R&D, while the private sector would pursue applied R&D and market development. However, unlike the communications industry, a multi-billion dollar market does not already exist. To find a company of sufficient size to be interested in making the investment required would demand that a market for resource sens ng products be fairly apparent. Showing that market may b a difficult task as many U.S. government agencies have said that a market price would sorely limit the adoption of Landsat technology by federal, state and local government users.[7] Therefore, a fourth factor that guides the policy process is the need to demonstrate that a sufficient market can be developed to support corporate investment in the space segment of an operational earth resource sensing system.

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[6] In private discussions with NASA personnel, I was told of the studies presently being undertaken as a part of the transition plan effort.

[7] see State and Local Government Perspectives on a Landsat Information System, prepared by the Natural Resource and Environmental Task Force on the Intergovernmental Science, Engineering, and Technology Advisory Panel, June 1978, pg. 36, hereafter cited as the ISETAP report.

This paper is an attempt to illuminate the constraints on
the Landsat market in developing countries. These const-
raints play an important role in potential market projec-
tions, and will therefore be important to understand as
policy regarding the system characteristics and govern-
ment/industry interface is made.

I intend to place the discussion of the potential Landsat
market in developing countries in the context of resource
information for development planning. The reason for this
is simple: resource information is essential to successful
development planning (in all countries, not just developing
countries). Landsat technology and products are one way
amongst several for acquiring that data, and Landsat may or
may not be the most effective and cost-efficient method
available. Hence, the real market which private sector
firms in this country must deal with is the market for
development planning, of which resource information is a
vital part. Therefore, building a viable Landsat market in
developing countries will depend on its use in development
planning, and such planning rests inevitably on the particu-
lar characteristics of the country involved.

This study is divided into four parts. Chapter 3 of this
study reviews the technology of Landsat, including the space
and ground segments. In much of the literature on remote

sensing, there has been an unfortunate overemphasis on Landsats' technology and potential.   Chapter 4 of this study concentrates on the user segment, and in particular,   on the constraints inherent in the development process which limit the market for Landsat data.   It will   generally point out that there is a "user need" for Landsat type data but that the development of that need into a viable market is constrained by present technology and indigenous factors.

Chapter 5 focuses on the institutional and political constraints impacting the adoption of Landsat technology in developing countries.

Finally, Chapter 6 will take a tentative look at the tradeoffs confronting U.S.   policy makers as they formulate Landsat po.icy in the context of the four guiding factors discussed on preceding pages.   At that point,   preliminary suggestions for future study will be discussed.

3.   THE TECHNOLOGY OF LANDSAT

In simplest terms, Landsat consists of three critical seg-
ments-- the space segment, the ground segment and the user
segment.   The space segment consists of the satellite, the
sensors, the ground based satellite control equipment and
software.   The ground system consists of data reception
facilities, data processing facilities and information
extraction/image interpretation.   A third critical segment
is the user community.   This segment is treated in Chapters
4 and 5.

3.1   THE SPACE SEGMENT

The Landsat satellite is a 950 kilogram spacecraft which
orbits the earth at an altitude of about 560 miles.   It
orbits the earth 14 times a day and returns to the same
orbit once every eighteen days.   The 14 strips of the
earth's surface covered each day by Landsat are each about
185 kilometers wide (115 miles).   Each day the satellite
passes over a strip 170 kilometers west of a strip surveyed
on the previous day, and senses it.   This provides a 15 km
overlap which can be important if there is a problem with

cloud cover or other atmospheric interference on any given

day. [8]

There are two sensor systems on all of the Landsat's which

have been launched to date.   Landsat's 1 and 2 each had

return beam vidicon (RBV) system and a multi-spectral scan-

ner (MSS). The RBV system consists of three television like

cameras aimed to view the same 185 by 185 km ground area

simultaneously. These cameras have a nominal ground resolu-

tion of 80 meters and the spectral bands designated bands

1,2,and 3 on Landsat cover the following parts of the elec-

tromagnetic spectrum:

             band 1   (green)   .46 to .60 um

             band 2   (red)   .57 to .68 um

             band 3   (near infrared) .66 to .82 um. [9]

However, on Landsats 1 and 2 the RBV systems were used rela-

tively little; they will be more thoroughly tested on Land-

sat 3. [10] The MSS records information in both the visable and

in parts of the electromagnetic spectrum which are invisable

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[8] Remote Sensing From Space, Prospects For Developing Coun-
    tries, National Academy of Sciences, Washington D.C.,
    1977, pg. 39,40.   hereafter cited as the NAS study.   see
    also Lillesand and Kiefer Remote Sensing and Image Inter-
    pretation, New York, John Wiley and Sons, 1977.

[9] NAS study, op. cit., pg 45.

[10] Ibid, pg. 43.

to the human eye and to the camera systems. The MSS takes
four readings for each 1.1 acre area on the ground--one for
the intensity of green light reflected, one for the inten-
sity of red light reflected, and two for the intensity of
infrared light reflected. The four bands of the MSS overlap
some with the bands of the RBV, but are designated as bands
4, 5, 6 and 7.   They cover the electromagnetic spectrum as
follows;

      band 4 (green)   .5 to .6 um

      band 5 (red)   .6 to .7 um

      band 6 (infrared)   .7 to .8 um

      band 7 (near infrared) .8 to 1.1 um

Landsat 3, launched in 1978, contained two major changes
from the previous Landsats.   First a thermal channel (10.4
to 12.6 um) was added to the MSS, and second, the spatial
resolution of the RBV system was improved to 30 m. However,
shortly after launch the thermal channel developed operating
problems, hence the MSS on-board the spacecraft is operating
in essentially the same mode as the previous Landsats.[11]
While the effective resolution of Landsat images is about
79m on the MSS images,   and about 30m on the RBV images,
depending on the interpretation technique being used, narrow
linear objects with distinct spectral characteristics can

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[11] Lillesand and Keifer, op. cit. , pg. 540.

often be detected.   On the other hand objects much larger
than 79m across may go undetected if they blend with their
surroundings so that features are not spectrally distinct.[12]

The space system also includes two wideband video recorders
which collect and store the data acquired in areas beyond
the range of the receiving stations.   This data is held
until the receiving station comes back into view of the sat-
ellite and is then dumped to the station. Each recorder can
handle either RBV or MSS data.   On Landsat's one and two,
only one of the four recorders worked regularly, making it
difficult to receive data from areas not in sight of the
satellite when it passed near a receiving station.[13]

The MSS has the following characteristics which make it dif-
ferent and sometimes better than conventional purposes for
remote sensing:

1. data is available in digital form making large
    amounts of data rapidly processible by computer;

2. the original data, in digital form, can easily and
    rapidly be transferred to other receiving stations,
    unlike a film original;

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[12] Ibid, pg 544.

[13] NAS Study, op. cit., pg 46.

3. they can acquire data in the infrared region which is
    beyond the capability of regular cameras.

However, the high resolution camera is still superior in
some cases for disclosing the identity, shape, and appear-
ance of many small objects or   features.[14]

3.2   THE GROUND SEGMENT

The ground segment involves three activities: data recep-
tion, data processing and data interpretation.

Data reception:

There are presently ten ground stations capable of receiving
Landsat data--of which three are located in the United
States, two are in Canada, and one each in Italy, Brazil,
Argentina, Japan and Sweden. The operators outside the U.S.
simply tell NASA when they wish to have the MSS turned on
over their station.   The station can receive Landsat data
while the satellite is within their "line of sight"--a
radius of about 3000 km.   This allows each station to
receive a total of about 28 million km sq. during one Land-
sat pass. (This is the total footprint of the Landsat as it
passes within the stations line of sight.)[15]

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[14] Ibid, pg 50.

Data processing:

There are three primary products which can be made out of

the Landsat data.   black and white imagery is produced at

the earth resources observations (EROS)   data center in

several forms: first, there are 55.8 by 55.8 cm.   negative

and positive transparancies at a   scale of 1:3,369,000,   and

18.5 by 18.5 cm film and print enlargements at 1:1,000,000;

second,   there are print enlargements 37   cm by 37 cm at a

scale of 1:500,000 or 74 cm by 74 cm at 1:250,000.[16] The

second Landsat products are color composites.   These take

advantage of the fact that the human eye can distinguish

many hundreds of color variations.   Hence, by applying dif-

ferent variations of colors to the variations of grey in the

negative, a color composite can be produced.

The third product developed from Landsat data are computer

compatible tapes (CCT'S).   These tapes preserve all the

intensity levels of the MSS (a total of 64) in digital form.

The CCT's can then be fed into a computer for digital analy-

sis of the spectral properties in order to produce desired

information in tabular form.   The tapes can also be used to
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[15] Issues and Options, op.cit.

[16] Ibid,   pg.   55.   A scale of 1:250,000 = 1 in/4 mi;
     1:500,000 = 1 in/8 mi; 1:1,000,000 = 1 in/16 mi.

produce thematic maps emphasizing one or another selected ground features.[17]

In performing digital analysis of Landsat data, there are three types of computer based procedures that can be used:[18]

1. image restoration: these operations act to "restore" distorted image data to a more "faithful" representation of the original scene;

2. image enhancement: prior to displaying image data for visual analysis, enhancement techniques can be applied to accentuate the apparent contrast between features in the scene. In many applications this greatly increases the amount of information that can be visually interpreted from the image data;

3. image classification: quantitative techniques can be applied to automatically interpret digital image data. In this process, each pixel observation is evaluated and assigned to an information category, thus replacing the image data file with a matrix of category types.

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[17] Ibid, pg. 56.

[18] Lillesand and Kiefer, Op. Cit., pg. 557.

Data interpretation usually begins with the detection and identification of important objects. The objects are then measured manually or with the aid of appropriate instruments. This measurement is then considered in light of the interpreter's particular expertise. Then the interpreter must be able to communicate both his perception of and the significance of the object identified.[19] Various methods of extracting information from remotely sensed data can be used. In sequence from least to most expensive and sophisticated they are:

1. manual interpretation of standard photographic products using very simple, inexpensive instruments;

2. manual interpretation aided by photographic enhancement and employing more costly optical equipment;

3. manual interpretation of special digitally enhanced photographic products using the equipment as described in step 2;

4. digital analysis of the computer compatible tapes in a process of man-machine interactions to produce the desired computer output, which is in turn subjected to further human interpretation and analysis.[20]

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[19] Estes, John, "A Perspective on the State of the Art of Photographic Interpretation", in International Symposium on Remote Sensing of the Environment, vol 11, ERIM, 1977, pg 161-176.

[20] NAS, Op. Cit., pg 55-56.

Finally, image interpretation and particularly information extraction may be aided by the "multi-concept" of data interpretation. This includes multi-station (Landsat, aerial, and ground surveys used together), multi-temporal sampling (different time periods using the same sensing unit), multi-stage sampling (which means simply acquiring data at different scales) and multi-band sampling (simply using different bands to look at the same scene).

Landsat's technology, from the space and ground segment provides at least five advantages over traditional surveying techniques. First, it views the earth synoptically; second, its repetitive coverage allows it to maintain up to date information; third, its computer compatibility allows its data to be merged with other information about population and terrain in order to produce more complete land-use and resource planning maps; fourth, its uniformity over time allows it to take comparative pictures which enhances the ability of planners to detect change. and fifth, its multi-spectral scanner allows it to observe different aspects of the same object, or to distinguish between two objects that might otherwise be missed. These advantages provide exciting potential. However, one must look to the user segment to determine if that potential will be realized.

4. THE USER SEGMENT, CONSTRAINTS ON MARKET DEVELOPMENT IN
                    DEVELOPING COUNTRIES

4.1   RESOURCE INFORMATION NEEDS IN DEVELOPING COUNTRIES

The ultimate objectives of collecting natural resource
information are

1. to aid countries in the evaluation of *investment* pro-
    spects;

2. to provide information to be used for improving cur-
    rent *management* of natural resources;

3. to aid in the performace of certain governmental
    activities (particularly the administration of land
    taxes and the like).[21]

I am primarily interested in the first two objectives, and
later on I will explore them in the context of a development
project.   However, a central question is: what kinds of
objectives and resource information needs drive developing
country investment and management decisions?   The following
examples suggest the types of development objectives out of
which the need for resource information is generated.

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[21] Herfindel,   Orris,   *Natural Resource Information for Eco-
      nomic Development* Resources for The Future, Washington
      D.C., Johns Hopkins Press, Baltimore, 1969, pgs 20-21.

Tanzania

Much of Tanzania's economic development effort is directed toward agriculture and animal husbandry. Principal resource data requirements in Tanzania tied to immediate needs include:

1. land use and land capability (distribution of soils and vegetation types) information to determine suitability for farming or range;

2. structural geology and groundwater information. as linked to soils, vegetation, and topographic data, to help locate additional water sources, to increase the efficiency of well digging and water impoundment schemes, and to help in the siting of new villages; and

3. monitoring of land and range stress due to drought or overgrazing to permit rehabilitation of these resources.[22]

Venezuela

Venezuela's development plans call for continued industrialization, further exploration of mineral and petroleum deposits, improved land use and quality of life in urbanized areas, colonization of frontier area, greater emphasis on investment in agriculture, including expanded assistance to the rural poor and placement of more land under irrigation. To accomplish these objectives, Venezeula's data collection efforts emphasize:

1. land use and urban change;

2. pollution assessment of beaches and coastal area;

3. further mapping of geologic structures to aid in mineral exploration and siting of mine related construction projects;

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[22] NAS Study, Op. Cit., pg.29.

4. classification of soils and vegetation in
    current and potential agricultural areas;
    determination of crop acreage and changes
    in crop and

5. monitoring of seasonal water coverage of
    lands being considered for new settlement,
    agricultural development and improvement.[23]

Costa Rica

The use of land for agricultural purpose; has been
the backbone of Costa Rica's economy for several
centuries. As Costa Rica's industrial and eco-
nomic base grows, increasing pressures are put
upon agricultural and range land, and in turn upon
the forest lands of the nation. Thus, prime agri-
cultural areas are being threatened by urban
expansion and areas predominantly suited to fores-
try are being converted to marginally productive
range and agricultural uses.

This conversion is not controlled or monitored.
Costa Rica's need for resource information in
order to control this type of urban spread is not
unique to developing countries. They require
information to monitor and update their land use
maps, in order to better manage their own domestic
growth and expansion.[24]

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[23] Ibid., pg. 30.

[24] Craib, Ken, et al., "Application of Remote Sensing Tech-
niques to Forest Vegetation Surveys in Tropical Areas and
Urban Fringe Land Use Problems in Costa Rica", in Inter-
national Symposium of Remote Sensing of Environment, vol.
12, pg 2081, 1978. (hereafter cited as ERIM symposium)

Sri Lanka

> In Sri Lanka, development planners in the mid
> 1970's began a program to develop new agricultural
> land in order to reach self-sufficiency in agri-
> cultural production and food consumption. Land-
> use maps had last been updated in the early
> 1960's, and many smaller farms were not recorded.

> The agricultural program has as its goals:

>> 1. crop breeding;

>> 2. multiple cropping;

>> 3. soil conservation; and

>> 4. improved management of agricultural lands.

> An agricultural base-mapping program was required

> to provide information on soils, present vegeta-

> tion, land-use for siting of new agricultural

> areas, and topography for assistance in irrigation

> planning and watershed management.[25]

The importance of natural resources to economic development

is clear, particularly as a country strives for self-suffi-

ciency. While trade enables many nations to acquire

resources which it does not possess internally, natural

resources and information about those resources is essential

in planning and implementing development projects.[26] Appen-

dix A contains a detailed list of resource information

needs.
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[25] "Agricultural Resource Inventory and Base Maping in Sri
Lanka, A Program Evaluation and Assessment", Resource
Development Associates, Los Altos, Ca., 11/76.

[26] Herfindel, Op. Cit., pg 4.

In order to successfully design and complete a development
project, then, knowledge of the resource base is essential.
This is the context within which the market for resource
information products in developing countries exists. In
sum, according to a national Academy of Science study,

> the process of economic development consists
> largely of organizing the development and prod-
> uctive exploitation of natural resources in the
> interests of the whole community. To do so effec-
> tively a nation needs to know what resources it
> has and where they are, and it needs to have a
> fairly detailed grasp of its overall physical
> environment. For many developing countries, this
> knowledge base is limited, fragmentary, dispersed,
> and on the whole, less than adequate for the pur-
> poses of sound national development. The capabil-
> ity to acquire, store, analyze and use natural
> resource information for broadly developmental
> purposes still eludes many developing nations.
> Most nations at present are seeking to acquire
> better resource information.[27]

The above quotation stresses that the type of resource
information needed varies not only with the type of resource
to be monitored, but with the end-use of that information as
well. The surveys themselves do not represent the end-use
of the data collected. Rather, the way data is used to make
decisions about resource management in particular and devel-
opment planning in general, represent the actual end-use of
remotely sensed data.

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[27] NAS study, Op. Cit., pg 24; See Appendix B for a discus-
sion of Landsat applications in developing countries.

4.2   THE DEVELOPMENT PROJECT CYCLE: CONSTRAINTS ON MARKET DEVELOPMENT

Developmental decisions are usually related to specific development projects.   Such projects go through at least four distinct phases, including project identification, project planning, project implementation, and project evaluation.[28]

The identification phase must be "carried out first to determine the human needs as well as the availability of renewable and nonrenewable resources required to prepare a development project."[29] The planning phase takes information on the nations infrastructure, existing capabilities, collected resource information and the countries political, social and financial status into account in designing an appropriate project.   This stage is followed by the implementation phase, which varies in length according to the type of project and the sector to which it is related.[30] The project evaluation phase, sometimes called the project appraisal phase, includes an on-going social, political, economic, institutional and financial analysis of the

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[28] Adrien, Pierre, and Alfonso Blandon, "Economic Overview of Remote Sensing Applications in Development Projects", in Proceedings of the Second Conference on the Economics of Remote Sensing, Craib and Watkins (eds.), Resources Development Associates, Los Altos, Ca., January 1978. (cited hereafter as Second Conference)

[29] Ibid., pg 21.

[30] Ibid., pg 22.

project.   In general The World Bank has found that the most
difficult phase of the project cycle is the implementation
of development projects.[31]

This problem continues to affect developing countries and is
directly connected to the project planning phase.   Whenever
the latter is poorly conceived.   the chance of successful
completion of a project become rather slim.

This   suggests that   as   countries   adopting Landsat   remote
sensing technology go through the development project phases
described above. appropriate utilization of Landsat technol-
ogy will depend to some extent on the wisdom and ability of
project   planners.   It   is   also   especially important   for
understanding the development of a Landsat market to realize
that   all phases   of a   resource   development project   cycle
require resource information.   particularly in the identifi-
cation and planning phases.[32] The following   chart outlines
the types of remote sensing applications used in the differ-
ent project phases. with the type of survey (to be further
defined in a moment) required at each phase noted to the
right.[33]

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[31] Ibid. pg. 22.

[32] See Appendix C for a discussion of potential Landsat
      applications in specific substantive areas pertinent to
      development.

[33] Ibid. pg 26. with my additions.

Illustration of Remote Sensing Utilization

in the Development "Project Cycle"

Project Phases or Cycles	Examples of Applications	Type of Survey
I. Project Identifi-cation	Natural resources iden-tification and quanti-fication; comprehensive resource inventory; obtention of timely reliable information through visual and digital analysis.	Reconnaissance
II. Project Planning	Examination of change in project resource base; assessment of potential benefits or problems.	Semi-detailed
III. Project Implemen-tation Monitor-ing	Role of technology rather limited, except if allocation and manage-ment of large volume of resource information are involved, such as natural or regional land use projects.	Detailed
IV. Project Evalua-tion (post)	Diversified uses in assessing the utiliza-tion of one or more natural resources in project development.	Combination of Reconnaissance, semi-detailed, detailed, depend-ing on project.

4.3   USER NEEDS: TYPES OF SURVEYS

Using the above chart we can divide resource information needs into three broad categories: reconnaissance surveys, semi-detailed surveys, and detailed surveys.[3] For each type

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[3] Other authors have used different labels for the various surveys. Throughout this paper I will use these, however they correspond to other common labels as follows: pre-investment=semi-detailed, inventories for operational

of survey, mapping requires progressively larger scale maps.
(See Table Below.)

Type of Survey	Map Scale
Detailed	1:15,840 (4 in./mile)
Semi-Detailed	1:20,000-1:63,360 (about 2 in./mile)
Reconnaissance	1:200,000-1:500,000 (about .1 in/mile)

Detailed maps are used, for example, in the use and manage-
ment of soils. Semi-detailed maps are required for agricul-
tural development projects, irrigation development, drain-
age, land enhancement decisions, and for determining
investment potential in agricultural development areas.
Reconnaissance surveys are used for identifying areas for
potential development activity.[35] However, these general
guidelines vary from resource to resource and country to
country. For instance, one study recently described agri-
cultural and forest information surveys as follows.[36]

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   management=detailed, and reconnaissance is usually just
   called reconnaissance.

[35] From informal discussions with personnel at Resources
    Development Associates. See also Herfindel, op. cit.

Reconnaissance--spatial/area information and data about the land

its natural condition, occurrence and acreage of

forest types, land use classes, crop types, etc.

(to be cited later as category A)

Semi-detailed---qualitative information about growing crop

species, tree species, species composition in

natural or cultivated stands of vegetation,

as well as about such stand quality aspects

as vigor, healthiness, timber quality, etc.

to be cited later as category P)

Detailed--------quantitative information and data about

cultivated stands of vegetation, or natural

but usable vegetation crops, timber volume

and age, plantation density, grazing capacity,

figures about the loss of a resource after

a disaster, etc. (also to be cited later as

category P)

The same study then produced the following table which gen-
eralizes, with respect to agricultural and forestry applica-
tions, the sources of various survey requirements.[37]

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[36] Hildebrandt, Gerd,   "Application of Remote Sensing for
    Policy Planning and Management in Forestry and Agricul-
    ture", in Earth Observation Systems for Resource Manage-
    ment and Environmental Control, Clough and Morley (eds.),
    Plenum Press, N.Y., 1977, pg 254.

[37] Ibid. pg. 255.

Survey Type   **Main Information Sources**

	Remote Sensing			
	Satellites	High altitude aircraft	Medium altitude aircraft	Ground level field work
Reconnaissance:				
very large areas,	A	A	A	A
broad classes,	P	P	P	P
less details.				
Pre-investment (semi-detailed):				
large areas,	A	A	A	A
refined classes,		P	P	P
many details.				
Inventories for Operational Management (detailed).				
small areas,			A	A
detailed classes,			P	P
very many details.				

Information Source Can Produce

A = Area mapping/classification
P = Properties, quantitative
    and qualitative.

Note that as one moves from reconnaissance to detailed sur-
veys, the information source and what it can deliver, shifts
from an emphasis on satellites to medium and low altitude
aircraft, and ground surveys. Hence, as one moves along in
the project cycle from identification to implementation,
satellites as an information source are likely to give way
to medium and low flying aircraft, and ground surveys. How-

ever, for appraisal and evaluation purposes throughout the
project, satellites may prove to be very important.[38]

In cutting into the resource information needs of developing
countries then,   we can segment the potential market for
Landsat products by the type of survey required.   With pres-
ent technology, Landsat is fully able to meet the reconais-
sance resource information needs of developing countries
(except where data is unobtainable),   and to partially meet
their semi-detailed/pre-investment needs (this is a particu-
larly grey area, depending to a large extent on the particu-
lar country involved).

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[38] I sho ld qualify this statement a bit, because depending
    on the sophistication of the ground processing equipment
    and the user, and depending on the country and resource
    involved, this generalization may not hold.
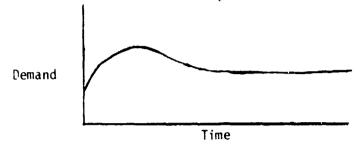
The Need For Repetitive Coverage

A closely related dimension along which the resource
information needs of developing countries must be assessed
is the frequency with which the data is required. For some
applications data need only be gathered every few years
while for other applications a survey may be required daily,
weekly or monthly. Appendix D shows the frequency require-
ments for several application areas. [19]
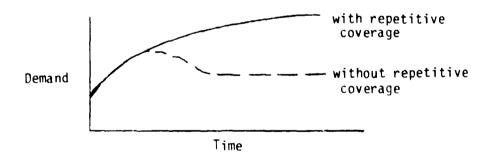
One trade off that is highlighted by the present study is
that the kind of survey for which Landsat is best suited
(reconnaissance) requires the least amount of repetitive
coverage. More detailed surveys usually require more fre-
quent coverage. So that while Landsat's 9 day (or 18 day
with only one satellite) frequency of coverage makes it
extremely attractive for some purposes, its relatively high
spatial resolution makes it less attractive for these same
purposes. The implications for the potential market of the
requirement for repetitive coverage are found in the market
projection presently being made by decision makers. If
one shot coverage at a reconnaissance level is all that is
required, the market will not grow in a linear fashion as

[19] Colwell, Robert, "Globally Uniform Resource Surveys", in
Earth Obervation Systems For Resource Management and
Environmental Control, op. cit., pg 194-195

assumed in current government projections. Instead it will take on the following demand growth curve. This curve reflects "one-shot" users who will order Landsat data once or a very few times, then drop out of the market.

As various technological requirements (mainly for finer resolution) for more detailed data are met, the amount of repetitive data utilized will increase (due to use of the data throughout all phases of the development project cycle)--and the demand growth curve will more fully approximate the "linear growth" projected by government policy makers.[40]

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[40] Issues and Options paper and PSIS study, op.cit.

4.4   <u>SUMMARY</u>

While development information needs exist for all countries,
the needs of individual countries vary according to several
factors, including the size of the country, its type of
geography, its development strategies and objectives, the
type of resource information already available, the degree
of detail that is needed, the present capacity of a country
to use resource information, and whether data will be
acquired once or repetitively.   In sum, in determining the
resource sensing information environment in developing coun-
tries, and hence the potential market for Landsat data, one
must consider the following:

1. At what stage in the development cycle is a project?
    Does that stage require reconnaissance surveys, or
    more detailed resource information?   In general one
    can think about the project cycle, extending along a
    continuum from project identification to project
    planning, project implementation, and evaluation.
    Generally as you move from development planning to
    project implementation the information needs become
    more specialized, calling for a closer and closer
    look.

2. Repetitive Coverage--Some projects require only
    infrequent resource surveys, while others will
    require them to be taken weekly, daily, or even more.

For instance, crop yield prediction requires at least bi-monthly overflight, while reconnaissance surveys may only need to be done every five years. Monitoring urban sprawl may require yearly pictures, while estimating disaster damage may require hourly response.

3. The type of resource to be monitored--some resources are more easily discernable than others, and this also will determine to some extent the timeliness requirement of the data. One particularly important determinant of the type of technology used for resource surveys, for example, is the simple or complex nature of the area to be observed. Appendix E outlines the difference between simple and complex areas in agricultural vegetation, range and forest vegetation, and geology, hydrology and soils.[1]

Along with the constraints of the resource development process and the type of resource to be monitored (and how often), one must also examine institutional and technological constraints when assessing the Landsat market. It is these constraints, as well as political questions regarding Landsat, to which I now turn.

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[1] Colwell, op. cit., pg 200,201.

5.   POLITICAL AND INSTITUTIONAL CONSTRAINTS ON THE DEVELOPING COUNTRY MARKET FOR LANDSAT PRODUCTS

Further constraints on the development of a market for remote sensing products in developing countries take the form of political concerns and institutional limit.tions.

5.1   DOMESTIC INSTITUTIONAL FACTORS

The operational use of Landsat remote sensing data is not constrained so much by technical concerns as it is by manpower, institutional and equipment factors.   It is in the routine use of data, not its collection, that the operational use of remote sensing data meets its toughest test.[42]

Therefore, there is a need to understand what internal insitutional and technological capabilities exist in a given country, and what type of interpretation and analysis procedures will best serve a developing country's needs.   In other words, one must understand the users present institutional environment to successfully build a user market in developing countries.   A recent survey[43] (the Wallender report) of technology transfer cases developed a useful typ-

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[42] NAS Study, op. cit., pg 117.

[43] Wallender, Harvey, et. al., Technology Transfer and Management in Developing Countries, Ballinger Publishing Co., Cambridge, Mass., see Ch. 3.

ology of user environments in developing countries: this
typology is summarized in Table 1.

TABLE 1

Development and Infrastructure

Stage Of Technological Development in Developing Countries	Objectives or Goals Within Each Stage That Must Be Achieved Before Proceeding To The Next Stage
1. Organization Development	1. Building an initial institutional structure.
	2. Building an internal problem solving and diagnostic planning capability.
2. Search and Acquisition	3. Problem Identifcation, and search for appropriate technology.
	4. Technology Acquisition
	5. Technology Application and use in decision making.
3. Maintenance and Modification	6. Maintaining and modifying technological and decision making structures as new technologies and problems arise.
4. Research, Development and Engineering	7. Development of internal technological capabilities.
	8. Spreading technology to other sectors of the country.

What the Wallender report suggests is that prior to building
a self supporting market for Landsat data in developing

countries, an institutional framework to support the use of
Landsat is essential. Transferring or selling technology to
end-users does little to help them achieve the objectives of
organization development (stage 1) or technology search and
acquisition (stage 2), and may in fact retard their movement
toward self-reliance in maintenance and modification of
technology and in R&D (Stages 3 and 4). The point is that
many international technology transfer projects have overem-
phasized technology (useful in stages 3 or 4) and have
failed to build an infrastructure or internal organization
to support continued use of Landsat data.[44] The Wallender
study concluded that efforts to build the technical capabil-
ities associated with stages 3 and 4 will fail unless the
objectives of stages 1 and 2 have been realized. Hence
critical to the development of a self-supported Landsat mar-
ket in developing countries is the development of indigenous
institutional and technological capabilities.

5.2   INSTITUTIONAL CONSTRAINTS

From the Wallander typology, we can see that prior even to
the development of the capability to identify problems and
to search for appropriate solutions is the need for organi-
zational development. This stage includes the building of

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[44] Craib, Op. Cit., 1973, pg. 290.

an initial organizational structure, and the development of
an internal problem solving and diagnostic planning capabil-
ity.   These two features of development may be thought of as
the major institutional and manpower constraints on techno-
logical development.   In the development of a long term mar-
ket for Landsat products in developing countries, these two
constraints must be overcome and effective strategies for
overcoming them may rely little or not at all on applica-
tions of Landsat technology.

Because one Landsat scene can be used by many interested
parties, including hydrologists, geologists, soils scien-
tists, agricultural specialists, physical planners, geogra-
phers, there are economies of scale in promoting multiple
uses of Landsat data.   According to the National Academy of
Sciences, "the more numerous and diversified the users of
remote sensing are, the more economically feasible it is for
a country to sustain a national analysis capability."[45] As
such, with the interdisciplinary nature of development plan-
ning coupled with the technology's demand for interdiscipli-
nary skills, the generation of organizational structures to
effectively house such activities is crucial.   Also, with
limited manpower and budgetary resources, a focused resource
information effort is needed.   There are many ways of

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[45] NAS Study, op. cit., pg 125.

coordinating such activity, depending on the country involved, its needs, resources, and political situation.[46]

Hence for the development of a long term market, the development of an organizational infrastructure is critical. As with any technology transfer project in this or any other country, the user must be trained to stand on his own once the transfer agent has finished his job. In this case the transfer agent, be it the U.S. Agency for International Development (AID) or some private consulting firm, will not succeed until the developing country has developed an internal organization that can decide on its own to use Landsat products and Landsat technology. This is where a potential market will be transformed into a viable market. In other words, a market requires demand pull as well as technology push. Foreign aid spent on transferring technology might be better spent in the development of an institutional/organizational infrastructure conducive to using remote sensing data. Without successful technology transfer efforts which start at stage 1 in the technology development typology, market building is likely to fail.

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[46] See ERIM Symposium, Vol 12, for a review of many national remote sensing programs. Appendix F reviews some of the various methods used to coordinate national remote sensing programs.

5.3   THE "FAMILIARITY WITH TECHNOLOGY" CONSTRAINT

Closely related to the development of an effective organiza-
tional context is the need to thoroughly familiarize the
users of the technology with the technology itself and its
value for helping them perform their work. This primarily
means training people and coordinating manpower and equip-
ment. Generally there are two types of training: general
and in-depth.

General training includes a balanced exposure to scientists
and policy makers of what the technology is and what its
limitations and advantages are. This type of exposure is
essential to starting a country on a road toward the adop-
tion of the technology. It usually preceeds a more formal,
in-depth training stage.

In-depth training involves coupling the training of special-
ists in the fields to be explored (water resources, geology,
etc.) with training in the interpretation of remotely sensed
data. This process may be quite extensive and take several
years. Such training is currently available from the devel-
oped countries and one concern of the developing nations is
continued access to training programs and facilities.

In developing a long term market--in creating both the
organizational infrastructure and internal problem-solving

capability--long-term, intensive training programs will have
to be implemented.   If this area is treated in a haphazard
manner, the potential for developing Landsat users will be
severely hampered.   In discussions with Dr. Charles Poulton,
former head of the remote sensing laboratory at Oregon
State, and consultant at various times to U.S. AID and NASA,
I was told of the importance   of training programs which
were intensive, hands-on, and long term enough to allow the
individuals involved enough time to develop the confidence
to "stand-alone." In his opinion this was one of the most,
if not the most,   critical step in building a market for
Landsat data products.

One particularly successful training program has been devel-
oped between the Laboratory for Applicatons of Remote Sens-
ing (LARS) at Purdue University and Bolivia.[7] As a result
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[7] This program includes the following features:

    1.   Short Courses: A one week long course on the fun-
         damentals of remote sensing.

    2.   Mini-courses: A series of modularized auto-tuto-
         rial units containing a broad range of sensing
         subjects that can be used in a variety of learning
         situations by students with diverse backgrounds.

    3.   Remote Terminal Network: Direct access to the
         LARS processing system is also available through
         remote termir..s.   A seven unit educational pack-
         age usable from remote terminals is available for
         user training;

    4.   Visiting Scientists: A specialized course, vary-
         ing from subject to subject, which offers in-depth
         training in various applications or scientific
         areas.

of this program, Bolivia now has a trained set of scientists who can perform their own analysis of Landsat data using sophisticated U.S. data processing equipment in their home country.[48]

The conclusions of this section are straightforward. The development of an effective market for Landsat products and tech-ology will rely on effective technology transfer that encourages developing countries to adopt Landsat technology. Such technology transfer will be successful only if it assists in the development of an effective organizational context.[49]

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[48] Bartolucci and Brockman, Second Symposium, op. cit., pg. 48.

[49] One firm, Resources Development Associates (RDA), having undertaken many projects in developing countries, has developed a multi-stage technology transfer process which includes

    1.   Identification of user information needs;

    2.   Demonstration projects which determine the most effective technological approach for obtaining the required resource surveys;

    3.   A pilot project which develops an internal operational capability and the information base responsive to the country's needs and its capabilities to operate and maintain that information base;

    4.   Implementation--the development of a national project to conduct resource information surveys and aid decision makers.

However, the adoption of Landsat technology in developing
countries also depends on political factors. It is to these
factors that I now turn.

5.4   POLITICAL CONSTRAINTS ON THE USE OF LANDSAT DATA IN
DEVELOPING COUNTRIES

There are three main areas of political and legal concern
that shape the development of a market in both developed and
developing countries. First, sovereignty issues: here there
are two foci, the question of whether a nation may engage in
remote sensing of the territory of another nation without
that nations consent; and the question of whether the sens-
ing nation has the right to transmit data generated from the
observation of the territory of one nation to a third nation
without the consent of the country sensed. Second, economic
issues: will resource information be used to the detriment
of the countries being sensed; i.e., will multi-national
corporations be able to further exploit a country's
resources to the detriment of that country's development
goals? Third, dependence and accountability issues: devel-

See "An Assessment of Resource Inventory and Environmen-
tal Problems in Costa Rica", Craib, 3/77, and "Design of
a Natural Resource Inventory for Costa Rica, Pilot Pro-
ject Report, 6/79, and Agricultural Resource Inventory
and Base Mapping program in Sri Lanka: A Program Assess-
ment and Evaluation", Craib and Cain, 11/76, (Los Altos,
Ca., RDA).

oping countries are reluctant to have to rely on a single
source for critical data. They are also concerned about who
will be accountable for the reliability and continuity of
the data. Here, I believe, are the most important issues to
be encountered. How can developing countries avoid further
and deeper dependence relations with developed countries,
and at the same time assure themselves continued access to
reliable and complete data?[50]

5.5   THE ISSUES OF SOVEREIGNTY AND ECONOMIC EXPLOITATION

There are two primary sovereignty issues discussed through-
out the legal and political debate in the United Nations
over the development of remote sensing regulations. First
is the desire of the developing countries to control the
sensing of their territory. A set of draft principles which
Argentina and Brazil jointly submitted to the U.N. Committee
on the Peaceful Uses of Outer Space of the UN states "that
states shall refrain from sensing the natural resources of

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[50] Before delving into these issues, one caveat is in order.
Throughout this policy discussion, it is essential to
remember, that while much talk goes on, the U.S. through
Landsat 3, continues to sense the entire world and to
make that data available to all countries. This should
be kept in mind because many developing countries have
shown that the use of Landsat to gather resource informa-
tion, with all of its question marks and political haz-
ards, is better than no information at all. By buying
the data at this point, they are undercutting their pri-
mary bargaining chip, which is the witholding of their
market from the U.S. companies.

another state without consent."[51] This issue is largely academic. Landsat technology is not bounded by the the relatively recent demarcation of state boundries drawn on the Earth. and to develop a sensor that could conform to such a demand would be prohibitively expensive. In any case, this move has been dropped.

Second, many countries desire control over the dissemination of data obtained about their country from remote sensing. This issue is the nexus of the argument in the UN debate; and a prohibition against open dissemination without consent is contained in the Argentina/Brazil draft, and also in the French Russian set of draft principles regarding control of remote sensing from space.[52]

Concern over dissemination stems from the fact that "nations seem to fear the economic imperialism of the technologically developed countries, particularly with regard to exploitation of Landsat discovered and hitherto hidden resource the existence of which might be unknown to a developing country."[53] This fear is questioned on three grounds:

[51] See U.S. Working Paper, "Remote Sensing of the Natural Environment of the Earth from Outer Space". UN Document /A.AC.105/C.2/L.103 (1973).

[52] See UN Document A.AC.1/1047 (Oct 15, 1974), Article IX of Latin America Draft Treaty. While positions on this issue have shifted, it is still a major point for debate.

[53] J.J. Hahn, "Development Toward a Regime For Control of Remote Sensing from Outer Space", in Journal of Interna-

> First, developing countries are entering into
> mature, mutually beneficial resource exploitation
> relationships with foreign interests, without for-
> swearing their rights to such ultimate sanctions
> as nationalization and/or expropriation. Second,
> the physical control of resources and of access to
> resource sites are the trump cards, not possession
> of tentative and unverified data. Third, as
> developing countries acquire their own remote
> sensing expertise, whether indigenous or procured
> from outside consultants, the margin of informa-
> tion disadvantage can lose a good measure of its
> significance."

The position of countries desiring a restricted dissemina-

tion policy runs directly counter to the U.S. position,

which is centered around the dissemination of remote sensing

data to all interested parties "on an equitable, timely and

non-discriminatory basis."" The U.S. further argues that

the imposition of dissemination limits would undermine two

of the most important benefits of satellite remote sensing

--the broad synoptic view of multi-national resources and

the development of global monitoring systems." The U.S.

believes that support of a restricted dissemination regime

neglects to consider the "tremendous benefits of remote

sensing and the fact that exploitation cannot really take

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tinal Law and Economics, no. 3, 1978, pg 449.

"" NAS Study, op.cit., pg 147-148.

"" Hosenball Speech to the American Bar Association, 8/8/73,
in Hood, Kimball and Kay, A Global Earth Observation Sys-
tem For Earth Resources: Problems and Prospects, (Ameri-
can Society of International Law, Washington D.C., 1977,
pg. 51.

"" NAS, op. cit., pg 147.

place without the knowledge and effective cooperation of the

country in which the resources lie."[57]

For some U.S. decision makers, however, concerns over disse-
mination impede the development of a global information sys-
tem.[58] These concerns also lay the base for international
pressures/demands on U.S. decision makers. This presents a
policy dilemma for U.S. decision makers.   On the one hand,
in the U.S., the position is taken that the U.S. government
ought to take the lead in establishing remote sensing
resource information as an international public good--taking
the information out of the hands of large U.S. companies
that might utilize such data/information.[59] In fact, this
position may well be in accordance with U.S. domestic policy
which allows open access to the data--and an open interna-
tional dissemination system would simply extend the domestic
system.   On the other hand, the private sector--if it is to
become involved in the ownership of the system--will likely
apply for some rights to the data, either through an exten-
sion of copyright laws or by making the data somehow pro-
prietary, in order to make the system profitable. While
this would not directly violate the open dissemination

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[57] Hosenball Speech, pg. 50.

[58] These include, among others, Senator Stevenson of Illi-
nois, and Howard Kurtz. See next footnote.

[59] Kurtz, "Remote Sensing of Environment, An Interdisc.pli-
nary Journal, Vol 6, Number 2, Editorial.

policy, it would make it harder and more expensive to use Landsat.

Generally then, within the U.S., policy makers are confronted with competing goals; first, for a government run global information system; and second, for a private sector dissemination system which will increase prices and encourage the use of Landsat data for economic gain. These competing goals interlock with the developing countries desire for reliability and continuity of data, which are free from political pressures. Here too, is a policy paradox. To avoid economic exploitation the elites of developing countries and of the U.S. may want governments involved in regulating the dissemination of information and its use; but to avoid political exploitation of developing countries, greater authority and control for the operation of the Landsat system should be located in the private sector,[60] or in some international organization.

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[60] This is not to say, unfortunately, that the private sector wouldn't use Landsat to politically exploit developing countries, however the fear is that they will use the data less for blackmail and more for economic exploitation of resources.

5.6   THE ISSUES OF DEPENDENCE AND ACCOUNTABILITY

The issues of dependence and accountability will probably

gain importance and move to the center of the policy stage

as the Landsat technology and market matures.   The issue of

dependence is clearly stated as follows:

> Should remote sensing technology fulfill it prom-
> ise, it will become indispensable for many coun-
> tries.   User nations will have made significant
> investments in facilities of various kinds.   They
> will have geared their data gathering and decision
> making processes, both in the public and private
> sectors, to the peculiar characteristics and
> assured availability of satellite imagery.   Their
> interest in the stability and continuity of the
> service on which their domestic systems will have
> come to rely will consequently be considerable.[61]

The impact that this issue has on the development of a

remote sensing market in developing countries is tied up

with the notion of international dependency.   Most third

world nations do not want, for political and practical rea-

sons to become dependent on one source of resource informa-

tion vital to their national planning--particularly a source

over which they have no control.   As dependence increases,

the demand for a voice in the planning of the system will

grow.   While in the short run the U.S. is in a dominant pos-

ition, the development of competitors in Japan and France

could dilute the U.S. hold on the market for remotely sensed

data.   If the U.S. doesn't consider the needs of developing

countries, and assure continuity and reliability of the

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[61] NAS Study, op. cit., pgs 149-150.

data, then when alternative sources become available--the
likelihood of a decreased U.S. market share increases.

The question of accountability suggests to some policy mak-
ers that the U.S. should acknowledge its use of space to
obtain resource information as the use of a "public commons"
for the purpose of obtaining a "public good." The use of an
international commons is to avail oneself of a public good.
Here, the international community view is that in the use of
such a commons, a nation should be accountable not only to
itself but to the interests of the larger world community.

This issue of accountability, it seems to me, is much like
the dependence issue. If developing countries demand a par-
ticipatory role in the development of a remote sensing sys-
tem, then by that simple fact they will have taken part in
the collective exploitation of the international commons,
and the issue of accountability will be easier to confront.
While at first blush this seems to be consistent with the
U.S. policy of developing space for the benefit of all man-
kind, it unfortunately runs into the problem of enticing the
U.S. private sector to participate in the development of an
opertional system. For if the research and development, and
the market development that an operational system demands
are dictated by international actors the ability to make a
profit could be impaired as the private sector is unlikely

to want to be held accountable to the desires of interna-
tional actors. This position also overlooks the tremendous
money spent by the U.S. to make the exploitation of the com-
mons possible in the first place.

In general then, while the U.S. has a monopoly at present
over the technology of remote sensing from space, and only
naturally wants to exploit that monopoly, the developing
countries (representing part of a viable market) wish some
say in the development of an operational system. While the
monopolist, in general, has to worry less than the small
competitor about user demands--in the case of Landsat this
may not hold. First, the technological monopoly is likely
to be short-term; and second, the market monopoly assumes
that a market exists to be monopolized. If the technology
does not meet the needs of the user, the user might not buy
what the technology has to offer, and the monopoly will have
nothing to monopolize.

The idea is the same as before: the U.S., in building a via-
ble market in developing countries, must take into consider-
ation, to some extent, the desires of the user--in this case
the developing world. To do this, the U.S. must try to
develop cooperative relationships, while at the same time
encouraging developing countries to adopt Landsat technol-
ogy.

6. POLICY ISSUES AND TRADE OFFS

The primary issue facing American decision-makers throughout
the debate over an operational earth resource sensing system
is the type of government/industry relationship that will
come to own and operate that system.   The market for Landsat
data and products is important to this issue because many of
the decisions on the pricing, timing and financial arrange-
ments for the operational system depend on that market.[62]
Unfortunately, a good market analysis has not yet been done.
The developing country market is an important potential mar-
ket, but is poorly understood.   This final section under-
takes some tentative analysis of the impact of U.S. policy
decisions on the growth of that market.

In general, there are four goals guiding the development of
Landsat Policy.   Two are international: the desire of some
U.S. policy makers to develop a global information system to
be used for peaceful purposes; and the desire of developing
countries to manage their own development.   Two are domes-
tic: the need to revitalize the U.S. economy in an economi-
cally hostile world; and the desire to move the operational
Landsat system into the private sector.[63]

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[62] See PSIS and Issues and Options Paper.

[63] see Introduction to this paper, pgs. 4-8.

Three primary policy issues will be addressed from the perspctive of these four goals; pricing, data ownership, and system characteristics.   The issues are simply stated. First, should the price of Landsat data be increased? If so, how much and how fast? Second, who should own rights to the data? The U.S. Government, the U.S. private sector, the user, or some U.N. body?   Third, what type of system should be flown?   One with maximum technical sophistication and highest cost, or a less sophisticated and cheaper system? These three issues can now be analyzed in light of the four policy goals just mentioned.

Policy I.   Pricing: In general an increase in the price of Landsat data and products will influence the international factors negatively and the domestic factors positively (at least in the short-term). (1) If a market price is charged for Landsat data, fewer Landsat applications will be cost-effective and this will dampen market growth.   (2)   An increase in the price of data is essential to capitalizing on the U.S. technological lead and encouraging private sector participation in the operational system.   Thus,   while a price increase is essential for private sector participation it may dampen the market building process.

In the short-term the building of the user community may be more important to the building of a long-term market than is

capitalizing on a short-term market. Further, as competitors come along,   a high price might allow them to capture some or all of the market.   In general, in thinking about the price of Landsat products,   one ought to consider the design of the system which will be extremely important in determining which users are most likely to use the system, and the sensitivity of those users to an increase in product prices.   Hence an understanding of the markets sensitivity to various system configurations and to price increases is essential.

Policy II: Data Ownership: If data ownership is taken out of the hands of the government and put into the hands of the private sector, international objectives will be negatively influenced and domestic objectives will be positively influenced.   (1) If the government gives the private sector data ownership rights, the ideal of a global information system will be unachievable.   Such a policy would make data proprietary and not reproducible by and for everyone.   While proprietary rights are important if private sector participation, is to be encouraged, such rights discourage an open, global system.   (2) Generally, the building of a user market would be hampered by making the data proprietary as the reuse or reproduction of data might be made illegal (although difficult to control).   Developing countries who might be encouraged at not having political strings on the data

(although the government seems to regulate much interna-
tional trade and technology transfer), may be wary of "eco-
nomic imperialism". (3) To bring the maximum return on
sales of Landsat data, ownership of the data and general
copyright laws are seen (particularly by industry) as essen-
tial. A decision in this area should include an analysis of
whether a market exists that could support a private sector
enterprise (in the best of all possible worlds). If there
is a potentially viable market, then some form of data pro-
tection may be necessary. If no viable market exists, then
a redirection of the program toward the meeting of global
objectives might be in order. Finally, this question is
tied up with the pricing question, data ownership should not
be undertaken without raising the price of Landsat data.

Policy III: System Characteristics: In general, the more
powerful[*] a system, the greater the positive impact on the
international objectives, and the more difficult it will
become (in the short run) to meet domestic objectives. (1)
The more powerful the sensing capabilties of the satellite,
the more useful it will be for global applications, and the
more important will become global coordination. (2) As
the satellite system becomes more powerful, it will meet
more and more user needs, thereby expanding the use of, and

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[*] Powerful referring to a system including maximum possible
   spatial and spectral resolution, plus stereoscopic capa-
   bilities.

interest in the data. By tailoring the system to user needs, the users will be more likely to support the system. (3) The cost of a powerful satellite becomes increasingly expensive. As this occurs, the potential for recouping U.S. investment, particulary in the next decade, becomes more problematic. (4) An increase in the the systems power, and hence in the systems cost, will make it harder to entice the private sector into ownership of the system. In general a powerful system is likely to generate a larger user commu- nity and make it harder in the short-term to encourage pri- vate sector participation. The U.S. should consider pursu- ing a more powerful system for several reasons; first, if they don't the French and Japanese are likely to try and take away whatever market exists in developing countries by tailoring their systems to developing countries needs; sec- ond, the U.S. is likely to fall technologically behind for- eign competitors; and third, in the long run it is likely that a more powerful satellite will be essential to the building of a viable market, as it will be usable throughout the development project cycle, and hence, for more repeti- tive uses.

Further issues can also be analyzed from this perspective. My general conclusion is that the building of a viable mar- ket in the short run, coupled with a strong R&D effort to maintain U.S. leadership in this area will insure a viable

situation for private sector participation in the long run. Short run factors pushing for "market now" strategies may hinder U.S. efforts to build global relations and to build a viable market. Policy makers must now get a firm hold on the market and its sensitivities to these various issues. In particular, I suggest the following areas for market study:

1. The extent to which the present market is supported by U.S. aid programs;

2. The probability that a viable market can be sustained through the continuation of such aid;

3. The determination of the real value of information from Landsat;

4. Market sensitivity to a projected four-fold increase in Landsat products;

5. Market sensitivity to the use of and cost of digital processing and interpretation techniques;

6. Market sensitivity to effective or non-existent user training programs;

7. Market sensitivity to different configurations for the operational satellite system;

8. The potential for aggregating a user market in developing countries which will be of sufficient size to help entice the private sector to take over some or all of the development and ownership of the system.

This paper has been an effort, in part, to understand the special problems inherent in developing a market for Landsat data and products in developing countries. Because of the great potential in developing countries, because of the importance to policy makers of understanding that market, and because it is so poorly understood--this should be an important item on the list of needed analysis for policy makers. Only when this and in fact the entire Landsat market is better understood, will policy makers be able to undertake to design the appropriate private/public sector interface for an operational Landsat system.

Appendix A

RESOURCE INFORMATION AREAS

Briefly, some of the areas where increased resource informa-
tion is needed are:

1. Agriculture--the need for accurate estimates of crop
    acreage and yields is critical to national and inter-
    national agriculural planning.   Land-use capability
    maps will prove useful in making decisions regarding
    what crops tc plant and where, irrigation and drain-
    age.   As such, soils maps, hydrologic maps, and gen-
    eral terrain maps will be important in constructing
    lan -use capability maps for agricultural planning.[65]

    As an aside, goals for global agricultural surveys
    might include:

    a) A global survey of cultivated areas, agricultural
       systems and crops to provide the statistical base
       for planning agricultural development and informa-
       tion for specific development projects, and to
       keep such information up to date.

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[65] NAS, op. cit., pg 38.

b) A survey of tropical Africa and South-east Asia of shifting cultivation and within these, the areas under cultivation and fallow, and as far as possible the age classes of the fallow as a guide to lengthening excessively short fallow periods and the resultant reduction of yield, due to increasing population pressure.

c) A global and desert locust belt survey to monitor conditions, mainly of weather and vegetation, potentially favorable for the development of crop pest epidemics in order to improve their control

2. Rangeland Management--Rangelands are important contributors to world-wide protein food supplies as they furnish grasslands for feeding of bovine, sheep, and goat populations. Between 40 and 60 per cent of the earth's land mass is covered with rangelands. They represent the largest reservoir of land available for conversion to more direct human use.**

However, due to rangeland characteristics, information is and has been difficult to obtain. "Practically no information has been available on rangeland conditions in developing regions."*' One necessary

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** User Needs, op. cit., pg. 15.

*' Ibid., pg. 17.

component, then, for improving rangeland management
is the acquisition of information on when, how much
and how long forage will be available.

> However, this information should be in the
> hands of range managers within about 10
> days after it is acquired. Like most plant
> systems, rangeland vegetation exhibits
> rapid changes in condition at certain sea-
> sons of the year and livetock movement can
> take appreciable time. Hence a need asso-
> ciated with the gathering of rangeland data
> is for the establishment of an effective
> system for rapid dissemination of rangeland
> information.[68]

Better range management information will enable

a) more accurate determination of germination and
   drying periods for planning movement of grazing
   animals to or from annual grassland ranges;

b) predictions of the remaining length of the green
   feed period made early enough to plan more effi-
   ciently for alternative sources of livestock feed;

c) comparison of conditions and relative forage prod-
   uction between grazing areas within a season, and
   comparison of conditions and productivity for a
   given area between seasons;

d) determination of the time when dry forage creates
   a fire hazard to better allocate men and equipment
   for fire suppresion.

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[68] Ibid., pg 17.

3. Forest Management--Information is needed in monitor-
ing clear cutting of forest by developing countries,
mapping burn areas, monitoring logging and detection
of pests and diseases.   In several developing coun-
tries the extent of deforestation has reached levels
far   exceeding   the   calculations   of   the   countries
involved.   Since   forests are an   important national
and international   resource,   information   about them
becomes all the more important in the face of present
inadequate information sources.

> Management   activities   require   information
> on   quantitative   standing   timber   values,
> patterns of stand structure and conditions,
> and dynamic response of   the forest.   How-
> ever,   traditional   data   acquisition   and
> processing procedures   have generally   been
> inadequate, slow, and too costly to produce
> the necessary   information to   meet current
> and projected   needs of   forest managers.[69]
> Forest   resource   inventory   information   is
> generally needed in 1 to 10 year cycles for
> forecasting forest trends and in the devel-
> opment of ong-term national programs.   How-
> ever,   for some   management purposes,   more
> frequent   observations   may   be   required,
> including:
>
> i)   detection of   stresses in   forest vegetation
>   to permit remedial action   before major dam-
>   age occurs;
>
> ii)   monitoring   of forest   harvesting   progress,
>   particularly in   remote areas   of developing
>   countries;
>
> iii)   determining forest response   to silviculture
>   practices such as fertilization and refores-
>   tation.

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[69] Ibid., pg. 17.

4. Water Resources Management -Since water is required
    by all humans for irrigation, sanitation,   power gen-
    eration,   and industrial processing,   and the demands
    for water in all these application areas is increas-
    ing in the face of growing world populations and
    increased demands for quality of life improvements,
    water resources information is essential. "Efficient
    water management may require a varied set of meteoro-
    logical and hydrological data: the volume of runoff
    and the variability of streamflows; the geological,
    soil, and vegetation characteristics of watersheds,
    possibly including data on the extent and depth of
    high mountain snow; the area watered by irrigation;
    and the rate of agriclutural use of water.[70] Improved
    water management capabilities require:

    a) maps of surface water bodies as small as several
       hectares to determine water reserves;

    b) mapping major river systems to determine their
       spatial variation and the seasonability of stream
       flow;

    c) surveying and monitoring of surface conditions in
       large watersheds;

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[70] Ibid. pg 17.

d) mapping of the extent of snow and ice-covered areas for runoff estimation;

e) mapping of the extent and duration of flooded areas as a basis for flood protection and land capability assessment;

f) surveying of estuary and coastal hydrologic features to determine dynamic water circulation patterns and water turbidity;

g) surveying of surface features as a guide to ground-water assessment.''

Such information will enable improved water resource management in these respects:

i) improved regulation of reservoirs for efficient hydropower generation, flood control, and water supply on the basis of better snowmelt and runoff prdiction;

ii) improved planning of regional water distribution based on better monitoring of surface water amount and soil moisture;

'' Ibid. pg 18.

        iii)   better decisions regarding irrigation man-
agement for crops through improved knowledge
of water consumption and supplies;

        iv)   more efficient and economic siting of
wells.[72]

5.   Minerals--Many parts of the world remain geologically
unexplored. As developing nations (and all nations
for that matter) become increasingly aware of the
importance of minerals for development, and aware
that they do not possess the detailed minerals maps
and information that developed countries do-- and as
they seek to assert their rights and ownership over
the development of minerals in their country, mineral
resource information becomes essential. Geological
mapping and terrain studies are a first step toward
mineral exploration, and provide a base for better
resource investment decisions.[73]

6.   Energy--In an effort to cope with high and rising
prices of energy, information on alternative energy
sources is becomming critical. For example, the
potential for hydrologlectric and geothermal energy

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[72] NAS. op. cit., pg 73.

[73] Smith. Willim. "Landsat Applications in Less Developed
Areas". in Remote Sensing Applications for Mineral
Exploration. Strousberg. Penn., John Wiley and Sons.
1976. pg. 279.

is/will be based largely on geologic and hydrological
data and such data only becomes available through
resource surveys. However, the primary thrusts of
applied geology have come where the discipline is
mature, the exploration area is accessible and the
cost of exploration is moderate.[74]

Because of these factors a disproportionate percent-
age of the known mineral deposits are found in the
temperate and arid regions of the world. However,
there is no geological reason why economic mineral
deposits should not be present in the tropical
regions in the same relative abundance as else-
where.[75]

7. Cartography-- There is a general need for basic maps
   fo· purposes of national and regional resource plan-
   ning. This includes information on urban sprawl,
   agricultural land withdrawl, siting or transportation
   and power systems, etc. General mapping needs are
   widespread:

   > Generally every agency within a Government
   > utilizes maps in one form or another for
   > resource inventories, land use planning and
   > control, urban area planning, energy devel-
   > opment and conservation, coastal zone and
   > wetlands management, environmental protec-
   > tion, etc. This is because Governments

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[74] Ibid, pg. 285.

[75] NAS Study, op. cit., pg 20,21.

cannot effectively function without precise
knowledge of the boundaries or the area
under their jurisdiction, the physical
characteristics of the country, the posi-
tion and size of urban areas, the communi-
cation network, etc.[76]

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[76] Ibid, pg. 13.

Appendix B

THE MAPPING POTENTIAL OF LANDSAT

The application of Landsat data and image interpretation to
many fields has begun to be demonstrated in developing coun-
tries.   The actual utilization of the data to help make bet-
ter or different decisions is less well demonstrated, and in
fact more difficult--this question is taken up in part 2 of
this study.   Here, I am more concerned with what types of
Landsat data can be produced and what their potential appli-
cability is; what is Landsats potental for solving resource
information problems in developing countries?

In general Landsat data can be used to prepare photomaps at
scales of   1:250,000 and   smaller,   particularly   with
state-of-the-art processing techniques. Generally for prod-
uction of basic maps at scales of 1:500,000 and smaller,
Landsats 1 and 2 (and Landsat 3 is) were quite acceptable.
With advanced digital processing techniques larger scale
maps can be produced (up to 1:24,000),   but the level of
detailed information which can be drawn more these maps may
make them unusable for some applications.   What my research
has shown, is that it is generally impossible to say whether

or not Landsat can do this or do that apriori to knowing

what the problem is.   For example, in some countries needing

general reconaissance surveys Landsat may turn out to be

inapp opriate because of the cloud cover.   In another area

where detailed information is needed, advance ground proc-

essing capabilities may make Landsat data quito useful, par-

ticularly in simply structured resource areas. What follows

are some examples of what has been done with Landsat in

developing countries to date.   The examples are meant to be

illustrative of the rich, however problem oriented, poten-

tial of Landsat.

Bolivia

1. The Institute Geografico Militar has prepared photo-
    maps at scale 1:500,000 from Landsat frames.   In
    addition, an uncontrolled mosaic covering the whole
    territory of Bolivia at scale 1:500,000 was produced
    using 65 Landsat frames.

2. Three different government institutions are involved
    in geologic studies using Landsat. Complete regional
    geologic maps covering one third of the country at
    1:250,000 have been developed. Using Landsat images,
    the government was able to select a number of poten-
    tial areas for oil exploration.

3. The government has also completed a map of the drain-
    age system in Bolivia at scale 1:1,000,000.   It is
    currently combining this information with geomorphi-
    cal data and geological data in order to identify
    areas of potential ground water accumulation;

4. Landsat imagery has also been used to produce a for-
    est map of the country at scale 1:2,500,000.   For
    further details maps at scales 1:250,000 are now
    being produced.

5. The government has done reconaissance soils st ⌣ /s
    at scales 1:250,000.

6. A comprehensive preparatory effort has been made to
    define land cover and land use types corresponding to
    the country's conditions.   The result has been a land
    cover/land use map at scale 1:4,000,000.[77]

Australia

1. Landsat colour composites are being used in the com-
    pilation of land-use maps at a scale 1:5,000,000 for
    the preparatiom of an Atlas of Australian resources:

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[77] UN, "Report on the UN/FAO Regional Training Seminar on
     the Applications of Remote Sensing from Satellite", La
     Paz, Bolivia, 1977, A/AC.105/210, pg. 5.

2. A complete set of Landsat aerial photomaps at a scale
    1:500,000 covering the whole of the state of South
    Australia has recently been completed.   These maps
    are intended for use in an ecological survey of that
    state;

3. The Division of National Mapping has also completed
    photomaps of the Australian Antarctic Territory' at
    scales of 1:500,000 and 1:250,000 from Landsat
    imagery.   These maps cover the main areas of topo-
    graphical interest such as coastlines and features
    free of ice and snow.[78]

4. A comprehensive land-use mapping program is underway,
    intially to cove. the South-Eastern part of Austra-
    lia.   Three "seperate overlays showing land cover,
    land tenure, and land use are being compiled.   False
    colour Landsat images of Bands 4,5 and 7 have been
    found to provide the degree of detail needed to dis-
    tinguish the different land cover patterns in most
    cases.   Where finer detail is required conventional
    aerial photographs are used."[79]

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[78] J.F. Ryan, "Applications of Remote Sensing in Australia",
    ERIM Symposium, Vol 2, op. cit., pg 47.

[79] Ryan, Op. cit., pg 69.

Argentina A number of projects were carried out in the province of Santa Cruz, using Landsat images for soils and actual land use studies as well as for economic and social studies of the area influenced by the construction of a big dam. For soils and geomorphological studies, Landsat imagery at scale 1:500,000 proved to be best suited under the topographic conditions existing in the Santa Cruz province.[80]

Chile

> Visual analysis of Landsat imagery at scale 1:500,000 and 1:1,000,000 was used in 1975 for the inventory of natural resources in the regions of Tarapaca and Antofagasta covering an area of 212,000 square kilometers. The geological interpretation of the imagery resulted in the identification of 10 areas with linear structures that justify a detailed prospecti onf on the ground. Geomorphologists identified 21 land forms each composed of 35 material components. For the first time vegetal associations could be mapped in these regions, discriminating seven formations and their respective subgroups. The interpretation of the Landsat imagery also allowed the delineation of several climatic zones and the separation of 43 watersheds. Pedologists were able to differentiate 56 soil associations.[81]

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[80] UN, "Applications of Remote Sensing From Satellite", op. cit., pg 7.

[81] Ibid., pg. 8.

Malaysia Land use mapping at scales 1:100,000 and 1:500,000

has been carried out. Using band 5 "broad land use delinea-

tions were possible and rice, rubber, mangrove, forest and

mixed agriculture were easily discernable.   Band 5 gives

greater tonal differences in vegetation cover than the other

bands."[82]

Brazil

> Flat areas with thin forest cover were considered
> to best suited for a transition into range land or
> agriculutral land with the excepton of very wet or
> swampy areas that had to be seperated out.   The
> selection of potential areas for the envisaged
> land use transition was made after studying the
> drainage pattern, the humidity and the density of
> forest cover in Landsat images of band 5 and 7."[83]

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[82] Salleh, Mehd, "Remote Sensing Activities in Malaysia", in
      ERIM Symposi 1, vol 12, op.cit., pg 135.

[83] UN, "Applications of Remote Sensing From Space", op.
      cit., pg 7.

Appendix C

LANDSAT POLICY APPLICATIONS

Soils Mapping and Agriculture

As part of a national water study of Mexico, soils maps at a scale of 1:1,000,000 intended to show the location and extent of the country's potentially arable soil resources, have been prepared largely with the aid of Landsat data. Two sets of Landsat color transparencies for most of the country provided the basis for the mapping project, which covered present land use as well as soil capability. The study of present land use covering the whole country took two years and cost $200,000. One significant finding was that 6.3 million hectares were in a state of advanced erosion. The study of soil capability covered 45 million hectares and was completed in one year. Thematic maps were extracted from the satellite data to indicate potential for cultivated crops and range, soil depths, wetness, slope, erosion hazard, and irrigation prospects. The maps now offer the Mexican Government a guide to the soils that are considered good or fair for development and that deserve more detailed study. For instance it seemed clear from the maps that some areas used for rice might be better suited for other crops and that the soils of the Gulf Coast area would be more suitable for rice production.[**]

[**] See A.A. Klingbiel and V.I. Myers, "An ERTS Based Land REsource Inventory for Mexico's National Water Study", Soil Conservation, 4:18-20 (November 1974) and H. Garduno, R Garcia Lagos and F Garcia Simo, "Present and Potential Land Use Mapping in Mexico", Proceedings of the NASA Earth Resources Symposium Houston Texas, June 1975.

Rangeland Management

A study in the Arusha region of Tanzania employed
Landsat data successfully in delineating boundries
for 550 distinct landscape units in a 32,000
square mile area on the basis of landform and vege-
tation characteristics. Fourteen grassland types
of varying suitability for forage were recognized
in the Landsat data. These delineations fortified
with detailed sampling information provided by
aerial photography and on-site inspections, have
identified promising areas for range, agricul-
tural, and ground water development.[85]

Forest Management

In Brazil, Landsat imagery has been used to moni-
tor a program for controlled development of large
areas of the Amazonian forest for various pur-
poses, especially cattle grazing. Landowners,
with the help of the government are permitted to
cut down trees up to a third of their land hold-
ings. Routine and systematic use of Landsat
imagery has proved to be the only economic way of
enforcing the terms of the government assistance
contracts and of monitoring and controlling the
volume of treecutting.[86]

Water Resources Management

Two series of Landsat images taken five weeks
apart made an important contribution to a multi-
stage study of the annual flooding of the Lower
Magdalena Cauca River Basin in Columbia. The
sequential images made possible a classification
of the river marginal lakes according to their
role in tempering the water wave and their poten-
tial for serving as reservoir basins. The Landsat
imagery was particularly successful in identifying
the lakes that dried up in the 5-week period. The
Landsat data, together with aerial photographs and
side looking radar images, yielded information
needed by governmental planners to determine the
most practical means to reclaim land in the lower
part of the inundated areas.[87]

[85] C.E. Poulton, et. al., "Potential Groundwater and Land
REsource Analysis for Planning and Development", Unpub
lished report prepared for the Agency for International
Development, 1975 cited in NAS study

[86] NAS study, op. cit., pg. 69

Geologic Survey and Mineral and Petroleum Exploration

On the basis of a rock-type classification map produced by digital computer processing of Landsat data, 30 prospect sites were chosen in a Pakistan area. Out of the 19 sites visited, 5 yielded evidence of surface mineralization, indicating the possibility of an enriched zone of copper.[88]

Land Use--Urban and Regional Planning

Comparative analysis of two sets of Landsat scenes covering the state of Orissa in India has yielded a substantial volume of land-use information of direct value to state resource managers and agricultural planners. The earlier imagery were studied primarily to locate areas of present and potential two-crop rice production, but also to identify as many land-use categories as possible. Indian soil technicians, foresters, and geologists, trained by a world bank team in interpreting satellite imagery by field survey methods, succeeded in recognizing about half of the thirty categories sought. The two sets of Landsat scenes highlighted the differences between dry and wet season agricultural patterns and identified promising areas for conversion to irrigated two-crop production. The Landsat data also indicated areas suitable for dams of barrages showed the extent of forest cutting in the highlands and coastal regions, provided a new base for checking the accuracy of crop acreage estimates done by conventinal means, and showed the changing course of the Mahanade River and its tributaries from the time of the last topographic mapping two or three decades earlier.[89]

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[87] E. Van Es, H. Gomez and R Soeters, "An Inundaton Study of the Lower Magdalena-Cauca Basin" in Houston Symposium, op. cit., 2295-2297.

[88] NAS Study, op. cit. pg 77.

[89] NAS study, op. cit., pg 79.

Appendix D

FOR AGRICULTURAL CROPS

10-20 minutes
Observe the advancing waterline in croplands during disastrous floods. Observe the start of locust flights in agricultural areas.

10-20 hours
Map progress of crops as an aid to crop identification using "crop calendars" and to estimating date to begin harvesting operations.

10-20 months
Facilitate annual inspection of crop rotation and of compliance with federal requirements for benefit payments.

10-20 years
Observe growth and mortality rates in orchards.

20-100 years
Observe shifting cultivation patterns.

For Timber Stands

10-20 minutes
Detect the start of forest fires during periods when there is a high "Fire Danger Rating."

10-20 hours
Map perimeter of on-going forest fires.

10-20 days
Detect start of insect outbreaks in timber stands.

<u>10-20 months</u>
Facilitate annual inspection of fire-breaks.

<u>10-20 years</u>
Observe growth and mortality rates in timber stands.

<u>20-100 years</u>
Observe plant succession trends in the forest.

For Rangeland Forage

<u>10-20 minutes</u>
Detect the start of rangeland fires during periods when
there is a high "Fire Danger Rating."

<u>10-20 hours</u>
Map perimeter of on-going rangeland fires.

<u>10-20 days</u>
Update information on "Range Readiness" for grazing.

<u>10-20 months</u>
Facilitate annual inspection of fire-breaks.

<u>10-20 years</u>
Observe signs of range deterioration and study the spread of
noxious weeds.

<u>20-100 years</u>
Observe plant succession trends on rangelands.

For Other Vegetation (mainly shrubs)

<u>10-20 minutes</u>
Detect the start of brushfield fires during periods when
there is a high "Fire Danger Rating."

<u>10-20 hours</u>
Map perimeter of on-going brushfield fires.

10-20 days

Update information on times of flowering and pollen production in relation to the bee industry and to hay fever problems.

10-20 months
Facilitate inspection of fire-breaks.

10-20 years
Observe changes in "Edge Effect" of brushfields that affect suitability as wildlife habitat.

20-100 years
Observe plant succession trends in brushfields.

Appendix E

SIMPLE VS. COMPLEX RESOURCE AREAS

Characteristics of simply structured versus complexly structured areas in relation to natural resources.

Simply Structured Areas

Agricultural Vegetation

1. Fields large, regularly shaped, usually homogeneous with respect to crop condition.

2. Few competing crops and cultural practices.

3. Little interspersion of cropland with noncropland.

4. All fields of a given crop planted on about the same date and hence developing in essentially the same seasonal pattern.

Range and Forest Vegetation

1. Blocks of rangeland and forestland are large and relatively homogeneous.

2. Elevational range is low to moderate and hence vegetation of a given type tends to develop with essentially the same seasonal pattern.

3. Few vegetation types present, all adapted to the same elevational and climatic range.

4. Topography flat to gently rolling so that few vegetational differences are the result of differences in slope and aspect.

5. Cultural practices with respect to range and timber resources are few and uniform.

Geology, Soils, and Hydrology

1. Geologic, soil, and hydrologic formations are relatively large, simple, discrete, and homogeneous.

Complexly Structured Areas

A. Agricultural Vegetation

1. Fields small, irregularly shaped, frequently heterogeneous with respect to crop condition.

2. Many competing crops and cultural practices.

3. Much interspersion of cropland with noncropland.

4. Fields of a given crop planted on many different dates and hence developing with many different seasonal patterns.

B. Range and Forest Vegetation

1. Blocks of rangeland and forestland are small and rel-
atively heterogeneous.

2. Elevational range is high to very high and hence veg-
etation of a given type tends to develop with many
different seasonal patterns.

3. Many vegetation types present, each adapted to a par-
ticular elevational and climatic range.

4. Topography steep so that many vegetational differ-
ences are the result of differences in slope and
aspect.

5. Cultural practices with respect to range and timber
resources are many and varied.

C. Geology, Soils, and Hydrology

1. Geologic, soil, and hydrologic formations are rela-
tively small, complex, intermingled, and heterogene-
ous.

Appendix F

METHODS FOR ORGANIZING NATIONAL REMOTE SENSING PROGRAMS

A first method involves the development of remote sensing

programs within an existing technical agency concerned pri-

marily with a particular resource.

> In Argentina, the primary interest of the first
> Landsat investigation has been to test space sens-
> ing capability to determine acreage and conditions
> of crops, especially wheat. The Ministry of Agri-
> culture amd Livestock has established a remote
> sensing opertion with an associated data process-
> ing center capable of both manual and computer
> processing Program plans include work in range
> management, agriculutal land use maps, and mapping
> of drainage networks.[90]

Secondly, in many countries remote sensing programs have

centered themselves in a lead agency that showed early

interest in using Landsat data.

> Brazil's highly advanced and well-equiped program
> is lodged in the Natinal Institute of Space
> Research. It operates a ground station which
> records more than 350 Landsat images a day, pro-
> vides data on agriculture and forestry to the Min-
> istry of Agriculture, on geology to Ministry of
> Mines and Energy, and on a broad range of subjects
> to the Ministry of the Interior , all of which
> contribute to the Institute's budget for these
> services. Other clients now include private firms
> and neighboring countries. The Institute has ties
> with educational institutions and runs its own
> seminars, workshops, and courses on remote sens-
> ing.[91]

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[90] NAS Study, op. cit. pg. 125,126.

Third, some countries have organized coordinating committees
to organize users and technical capabilities prior to the
establishment of a full-blown program.

> The National Committee on Mineral Exploration and
> Survey Operations in the Philipines has served as
> a coordinating agency for remote sensing activi-
> ties. The coordinating body includes several
> bureaus including some out of the Departments of
> Agriculture and Natural Resources, The Coast and
> Geodetic Survey, The Air Force, and The University
> of the Philipines. Thus far, this committee has
> dealt with Landsat programs in the areas of geol-
> ogy, land use, hydrology, cartography and mineral
> exploration.[92]

Finally some countries have simply developed new agencies to
organize and take responsibility for remote sensing activi-
ties.

> The Indian Government established the National
> Remote Sensing Agency in the Department of Science
> and Technology in 1975. It has plans to orbit an
> earth survey satellite with a return beam vidicon
> sensor at some point in the future. Its goals are
> to guide remote sensing research, maintain data
> banks, publish research results, organize training
> programs, and conduct resource surveys for use by
> the countries development planners.[93]

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[91] NAS Study, pg 126.

[92] ERIM Symposium, Vol 12, See pg 128-138.

[93] ERIM Symposium, Vol 12, see pg. 43-53.

LANDSAT: HISTORICAL OVERVIEW AND POLITICAL ANALYSIS

Matthew R. Willard
August 1981

Abstract

The previous paper, "Understanding the Landsat Market in Developing
Countries" discussed the potential Landsat market in developing coun-
tries. The discussion addressed Landsat in the context of four political
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global development, (2) effective U.S. foreign policy, (3) domestic
economic growth, and (4) private sector involvement in an operational
remote sensing system--stem from a mix of domestic, foreign policy and
international concerns. As an extension to that earlier study this paper
undertakes a political systems analysis which explicitly recognizes and
takes into account those often-competing goals.

To accomplish this task, and to illuminate the policy trade-offs
facing U.S. decision makers, this paper proceeds through three stages.
The first stage briefly discusses Landsat as global technology, as a
driver of global interdependence and a harbinger of the types of issues
which are likely to populate policy agenda in the future. The second
stage reviews the historical development of Landsat policy, both domestic-
ally and internationally. Finally, a policy analysis framework is applied
to the historical interpretation laid out in the second stage.

A WORKING PAPER

LANDSAT: HISTORICAL OVERVIEW AND POLITICAL ANALYSIS

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LANDSAT: HISTORICAL OVERVIEW AND POLITICAL ANALYSIS

Overview

An earlier work, "Understanding the Landsat Market in Developing Countries" (Program in Information Policy, Report No. 30, November 1980), discussed the potential Landsat market in developing countries. That discussion addressed Landsat in the context of four political and economic goals constraining U.S. policy makers. These four goals--(1) global development, (2) effective U.S. foreign policy, (3) domestic economic growth and (4) private sector involvement in an operational remote sensing system--stem from a mix of domestic, foreign policy and international concerns. As an extension to that earlier study this paper will undertake a political systems analysis which explicitly recognizes and takes into account those often-competing goals.

To accomplish this task, and to illuminate the policy trade-offs facing U.S. decision makers, this paper will proceed through three stages. The first stage will briefly discuss Landsat as global technology, as a driver of global interdependence and a harbinger of the types of issues which are likely to populate policy agenda in the future. Second, I will review the historical development of Landsat policy, both domestically and internationally. Finally, I will apply a policy analysis framework to the historical interpretation laid out in Part II. This will serve to illustrate the type of policy analysis I think is necessary for understanding global technologies in an era of international interdependence.

This paper will serve the reader in two ways. First, Part II can be read for its historical value and whatever it adds to the readers understanding of this important technology. More importantly, I hope, the reader will be able to take the framework of analysis and think constructively about Landsat and other issues from a slightly different perspective. If this paper accomplishes these things then it will add to policy debate rather than cluttering it more than it already is.

Part 1. INTRODUCTION [1]

In 1972, the National Aeronautics and Space Administration (NASA) launched the first earth resources technology satellite (ERTS); an unmanned satellite to provide information about the earths resources and environment on a global basis. The ERTS system (later renamed the Landsat system) holds great potential for providing widespread human benefits in the areas of resource planning and exploration and environmental monitoring.

Landsat is a global technology, a technology whose technical aspects and socioeconomic effects have a major transnational component. But which is developed largely from a national base. Leonard Jaffe explained its technical side to the United Nations this way:

First, satellite sensors are not capable of distinguishing national boundaries. No nations are clearly demarcated, except island nations, by natural features around their entire perimeters.

Second, as a technological matter, we do not know how practically to disentangle images taken by a remote sensing satellite on the basis of political boundaries ... we do not forsee the time when compartmentalizing data processing on the basis of national boundaries would be either economically feasible or technologically acceptable.

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[1] References will be listed in parenthesis following the appropriate sentence. The first symbol (i.e., C-) refers to the appropriate reference found in the "Sources Consulted" section at the end of this paper. The second symbol (i.e., p. 1) refers to a particular page, where appropriate.

Third, the wide scope of the area covered by the satellite will in most instances unavoidably entail the sensing of at least parts of several countries. Technically we cannot now or in the foreseeable future limit or shape the reception capability so that data would conform to political boundaries (C-50, p. 4).

Landsat's global basis is also reflected in the wide range of participants in the policy process--more explicitly the many parties who must be taken into account in the policy process. Other examples of global techologies include communications satellites, weather satellites, international data networks, seabed mining technologies, and international transportation technologies.

The politics of global technologies are complex. The interests are many, and the problems to be dealt with in developing policy on both the national and international levels enormous. In developing policy on a future operational earth resource sensing satellite system, it is not surprising that the following range of interests must be considered:

Technical Interests

-   Remote Sensing provides the opportunity to learn a great deal about the physical aspects of the earth on a global and regional basis. Current policy stresses the importance of basic research in the Landsat program;

-   Landsat provides the global and regional information which could become central to solving national and international resource and environmental problems;

-   The continued improvement of remote sensing technology will spin off technological improvements in other areas, including information processing, interpretation techniques and forecasting models.

Public Interests

-   Earth resource information derived from Landsat images can make significant contributions to the functions of many Federal agencies in areas as widespread as crops, weather, climate. geography, geology, map making, land use planning and monitoring, environmental protection, etc. The potential is for Landsat information to make the jobs done by the Federal Government cheaper and more effective.

-   The broader public interest needs of the U.S., including the use of Landsat data by state, local and regional governments, and by Universities for resource monitoring and compliance with Federal environmental and other regulation, are many. The use of Landsat to meet those demands at reasonable cost, and in an efficient manner, is possible.

Private Sector Interests

-   The use of Landsat data can be used to the advantage of U.S. industry in many areas, particularly in the field of oil and mineral exploration.

- With the potential for commercialization of remote sensing technology and products, the U.S. is in a position to utilize its competitive advantage in space technology. It is clearly in the U.S. interests to maintain a technological lead in space technology and particularly in remote sensing technologies, where some believe an enormous market will develop.

- The potential of Landsat pictures for contributing to the economic growth of both the developed and developing world through appropriate use in development planning and resource exploration is large.

U.S. International Interests

The use of satellite remote sensing data by many countries in the world suggests that Landsat may be a positive tool for use in supporting U.S. foreign policy efforts. Promises have been made by U.S. presidents to make remote sensing data available to the developing countries along with technical aid.

- The U.S. has pioneered the use of satellites for gathering resource information. It is important to the prestige of the U.S. and its ability to lead the international community that it maintain leadership in space activities, particularly in areas of such tremendous human applications potential.

- Landsat presents the U.S. with a tremendous opportunity to enhance its position with the developing countries. In particular, in regards to technology transfer, Landsat presents an opportunity to carry through many promises of technology aid to developing countries.

- Space has provided an area of a great deal of international cooperation. It is generally in the U.S. interest to maintain that cooperation. Also, many developing countries and other developed countries have made substantial investments in ground equipment to be used with Landsat. It would be in the general interest of the U.S. to see the program through and not see the investments of those foreign countries go to waste.

- The development of international institutions to deal with global problems has a long history. The Landsat system presents another area in which international cooperation is important. It provides an opportunity to innovate institutionally--to try and find workable international arrangements for dealing with international issues.

Foreign Interests

- Many foreign countries, particularly developing countries, are now using Landsat operationally for mapping and as an input development planning processes. These countries strongly desire availability and continuity of high quality data, while minimizing dependence on the U.S.

- These same countries are concerned about sovereignty over national resources and data about those resources. A restricted data dissemination regime[2] has been discussed.

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[2] Such a regime would impose restrictions on the sending of data gathered by one country, about another, to a third party.

-   There is a concern that data from remote sensing satellites will be
    used to help the developed countries economically exploit the
    developing countries.

-   There is a concern that space exploration will become overly
    competitive. As such, some countries are pushing for a cooperative
    international regime.

-   Foreign countries are developing their own highly competitive systems
    for remote sensing and will provide data and services competitive with
    those offered by the U.S. They may also be looking for economic gain
    from resource sensing satellites.

    It is this set of domestic, foreign, and international interests which
give rise to the competing goals and issues facing U.S. policy makers. In
this paper I intend to look at the policy tradeoffs amongst the interests
outlines above.

Summary - Part I

The politics of Landsat, and of global technologies in general, are
complex. The interests involved are many and the problems to be dealt with
in developing both national and international policy difficult and
interconnected. How can the complex and interdependent politics of global
technologies be analyzed? It is to this question that I now turn.

Part II. AN INTERPRETIVE HISTORY

What follows is an interpretive history of the development of Landsat policy. It proceeds through various stages--in both the national and international realm--in an effort to suggest the trends and patterns which will highlight in the analysis/evaluation which follows.

Stage 1: The Bureaucracy in Action: The Emergence of Landsat

The United States Civil Space Remote Sensing Program began in 1960 when the first remote measurements of the earth by satellite were made by the Television Infrared Observation Satellite (TIROS-1); a meteorological satellite launched as a precursor to todays operational weather statellite system (C-13,6). "Activity in the earth's resources area within NASA dates back to at least 1964 when the manned spacecraft center at Houston commenced a program of aircraft flights to define possible sensor systems for remote sensing use" (C-35). In 1964, NASA also set up a photographic advisory team which recommended the flying of a metric camera to do base mapping. However, the Department of Defense (DOD) liked the idea so much that it disappeared behind the classified door (C-32, 362). However, it seems that restrictions on military technology caused few problems for the developing earth resource program because military technology was not well suited to studying earth resources (C-6, 4). In the early 1960s with the U.S. emphasizing a civilian space program, separate from the military, with the success of the first weather and communications satellites, and due "to the fact that spy satellites were neither suitable or available, much of the

impetus for Earth Observations Satellites for civilian purposes came from

early NASA manned programs and weather satellites" (C-6,5). It was,

however, in conjunction with the military, that initial spatial resolution

limits were decided upon (C-6,5).

At their inception, earth resources satellites were without a natural

constituency in the government or in the general public. Therefore, NASA,

being strictly an experimental agency, reached out to tie its program to

other, user-oriented agencies. In that same year, 1964, NASA moved $100,000

to the Department of Interior to undertake preliminary studies of satellite

potential for earth resource surveys; in 1965 similar funding was supplied

to the Department of Agriculture and the Naval Oceanographic Office (C-6,6;

C-15; C-31,30) while the total for all these studies was only $400,000

($100,000 in 64, $300,000 in 65) the cat was out of the bag (C-41, 669).

The door was now open for bureaucratic pressures to work to move the

program. However, an initial agreement was not forthcoming as the Interior

Department was particularly interested in spatial resolution and base

mapping, while the Agricultural Department concern was with automatic

spectral recognition (C-34,34); the ability to determine crop varieties

depends not so much on fine-grained pictures as it does on the ability to

show different spectral signatures. While both user agencies wanted a

smaller, less sophisticaed, operational satellite, NASA was interested in

flying a large, highly experimental satellite--in line with the 'manned'

emphasis of its overall programs. NASA added that a mapping camera would be

an operational system, and not NASA's responsibility (C-32,363). During

1964-65 then, NASA developed three study versions of an earth resources

satellite--a small, a medium and a large orbiting earth resources orbiting

satellite. NASA dropped the small version from its studies until 1966 when

it was put back into the study program under pressure from the user agencies

(C-34,34).

In 1966 the program gained momentum. NASA asked the Interior

Department's United States Geological Survey (USGS) to expand its support of

NASA's Earth Resources Program. The USGS went to the National Academy of

Sciences, National Research Council (C-41, 66a) which undertook a study on

the "Useful Applications of Earth Oriented Satellites." This study later

suggested that the Earth Resources Satellite would "have a revolutionary

impact on land management and environmental planning" (C-47). In fact, the

NAS study recommended the same thing as a NASA team which had been working

concurrently on feasibility studies.

In late spring of 1966, a Geographic and Cartographic applications

program was established at the USGS, through NASA (C-31,30). Two NASA

people were assigned to work with the program at the USGS and they managed

to convince the Director of the USGS, William Pecora, of the merits of earth

resources satellites. They also convinced him that it would be a good

political move for Interior to take the initiative. Pecora then convinced

then Secretary Udall to "launch the issue" (C-6,9-10). On September 21,

1966, Secretary of the Interior Udall announced the Earth Resources

Observation Satellite (EROS) program. He made every effort to make it an

Interior initiative by stating "that the Interior Department should be the

prime decision-making agency on the goals and execution of the program" and

that "NASA should supply the needed expertise in sensor and space flight

engineering" (C-41, 66a; C-31, 30; C-1,3). NASA quickly and angrily
responded that "before a fully worked out program to use operational systems
can be approved, a long period of experimental work must take place" (C-15,
C-1,5). However, during this time NASA bowed in part to this pressure by
moving responsibility for its own program, the Earth Resources Technology
Satellite (ERTS) program, from the Office of Manned Space Flight to the
Office of Space Science and Applications (C-1,5). This shifted the program
to the Goddard Space Flight Center (GSFC), an applications, as opposed to
manned flight, center. This seemingly small bureaucratic shuffle was
actually very important as it brought ERTS out from under the Apollo
program. While this initially might have been detrimental (as I will point
out shortly), in the long run it enabled the program to attract supporters
and move forward under its own auspices.

The Interior Department continued to push. On October 21, 1966 it sent
to NASA its performance specifications for the satellite. They wanted an
operational system by 1969. NASA argued for an unhurried appraisal
(C-6,12-13;C-1,5). While these initial specifications were put forward only
as a straw man, when ERTS-1 eventually flew it met most or all of them.

NASA, through the GSFC, undertook a set of feasibility studies
regarding the use of unmanned spacecraft for earth resources experiments
(C-31,30). They later reported that such a satellite was not only feasible
but could be put into orbit in 1970 (C-1,5). On the basis of this study,
the Office of Space Science and Applications (OSSA) prepared a program plan
which included a mapping imager and a multispectral imager. This plan
responded to both the Agriculture Department which had requested a

Multi-Spectral Scanner (MSS) and the Interior Department which pushed for a Return Beam Vidicon (RBV) mapper (C-6,14). A compromise was reached to include both as each agency wanted its own, small economical satellite, and NASA wanted to test numerous sensor systems (C-6a,8; C-6,14).

In October of 1967 NASA submitted a $17 million new start in the Earth Resources area; the Bureau of the Budget (BOB) completely rejected it. They cited the following reasons: First, "an earth resources satellite may actually cost more than other methods of providing the same benefits;" second, "past studies have not adequately focused on the specific actions by which satellite acquired data would be used to create savings and benefits;" and third, that, "studies and plans should cover the organization and systems involved" (C-15). One could look beyond this official response to note pressures for keeping the budget down; experience with new projects which promised a lot but delivered little; and because CIA and military people working in OMB thought such a program would draw attention to U.S. spy satellites (C-6a,11). In addition, NASA could be faulted for pushing a new start instead of attaching the ERTS program to one of its already accepted applications programs, as new starts always attract heavy budget scrutiny (C-15).

As a brief sidelight to this tale of bureaucratic machinations, it is useful to point out that international involvement had already begun. In 1966, in a letter from NASA Deputy Administrator Services to the President Special Assistant Rostow, NASA outlined a rationale for pre-ERTS pilot projects including foreign countries. This rationale included the support of U.S. international policy objectives and an effort to generate interest

in the program in foreign countries (C-32). In December of 1967 the

President of Indonesia asked the Secretary General of the United Nations,

U. Thant, to help expedite the program (C-31,30). In 1968 initial, aircraft

remote sensing projects were started with Mexico and Brazil (C-8,10). These

activities would bring the State Department and the Agency for International

Development into the bureaucratic scramble. Already, prior to the approval

even of a test satellite, international relations had begun to be joined to

the bureaucratic political machinations.

In sum, the slow evolution of ERTS was not a technical problem.

Instead it stemmed far more from "budgetory constraints and bureaucratic

infighting" (C-1,2). Why was there such a delay? NASA had the ball but

had no quarterback (C-1,3). They were dominated by manned spaceflight

programs and saw little benefit in ERTS; believing that the Interior and

Agriculture departments would probably get the credit (C-1,11). In fact,

it wasn't until the moon shots ended, under pressure to produce

earth-oriented applications, that NASA became an ERTS proponent. Then NASA

ran smack into the Office of Management and Budget (C-1,7).

Following the BOB rejection, Congress--in order to keep the program

from stalling completely--got into the act. Following Congressional

hearings in March 1968 on Earth Resources Survey Program requirements, the

Congress urged vigorous pursuit of the program (C-15). They were, contrary

to the BOB, willing to go ahead wih the development of a system without a

clear idea of the future domestic or international institutional

arrangements which would accompany the technology--given that it realized

its potential. A battle line had been drawn between going ahead with the

technology and allowing the institutions to catch up--or moving them ahead simultaneously.

In response to Congressional prodding, the Earth Resources Survey Program Review committee (ERSPRC)--including NASA, Agriculture, Interior, Commerce, and the Navy--was estblished for interagency coordinating purposes in July 1968. In February 1969 this committee approved final design specifications for ERTS-1 and in May 1969 sent requests for proposals to industry for doing the design work--General Electric and TRW won the design study contracts (C-6,23; C-31,31).

At the Congressional Hearings for FY 1969 on the ERTS program, the 'private sector' testified that the program was technically feasible and ought to go ahead (C-15). In fact, one company suggested that "... ERTS can be readily derived from an existing flight proven satellite, with a minimum of modification. This is almost an off-the-shelf technological opportunity" (C-28,504).

Congress put $5 million into the FY 1970 budget for EROS (and for sensor development) but "the OMB impounded $3.9 million of the allocated funds and as a result the project ran into financial difficulties (C-13, 17). This eventually burdened the Interiors ability to provide high quality data from ERTS-1 (C-6,22). The OMB had set NASA up for a Catch-22. "It had to conduct only an experimental scientific project, but could justify it only on the grounds of its eventual practical uses" (C-6,12). By holding back EROS funds, the OMB had made it particularly difficult to run successrul projects and generate the high cost-benefit return the OMB required.

Finally, on July 15, 1970--after six years of debate--GE was awarded the contract to design and build ERTS-A. It flew on July 23, 1972.

As the program got underway, experiments were needed to test the satellite's usefulness. At this stage, NASA chose to fund hundreds of small experiments and provide data to any serious experimenters who would provide their results to NASA. In doing so NASA ended up reaching out to state and local governments, universities, foreign countries and other ultimate users (C-6,27). In all, 98 principal invstigators in 37 countries were selected (C-8a,10). These experiments provided a base for a growing and positive interest in satellite remote sensing, throughout the U.S. and the world. It is these experimentors, in part, who would later shape the development of Remote Sensing policy.

In sum, ERTS-1 represented a set of compromises; between a conservative approach to the state of the art in the late 1960s ... i.e., tight budgetary limitations, a relatively unfocused user community ... and concern over international reaction to the general availability of high quality earth resource survey imagery (C-9c, 162) and between NASA and the user agencies involved (C-35).

Into The International Arena

In 1969, President Nixon formally introduced ERTS to the international community. In the traditional spirit of the U.S. space program, he stated that the ERTS "program will be dedicated to produce information not only for the U.S. but also for the world community ... such an adventure belongs not to one nation but to all mankind and should be marked not by rivalry but by

the same spirit of fraternal cooperation that has long been the hallmark of the international community of science" (C-48, 301). On December 10, 1969 the U.S. ambassador to the UN, William Buffum, further elaborated U.S. policy:

1.   The U.S was "happy to offer technical guidance to member states who may wish to pursue aircraft based sensing programs;"

2.   The U.S. provided copies of the detailed descriptions of the earth resource survey program;

3.   The U.S. would expand NASA's international fellowship programs to include remote sensing training at the university level;

4.   The U.S. would provide briefings and exhibitions of earth resources surveying techniques;

5.   The U.S. would convene an international workshop on earth resource survey systems to provide interested agencies of other nations an opportunity to acquire substantive information about remote sensing equipment, techniques, and applications; and

6.   Would "invite international users to work with the U.S. as we explore the best ways of approaching such technically difficult matters as data processing, interpretation and dissemination" (C-49; C-5, 60-62).

On December 16, 1969 the UN recognized the development of remote sensing technology (UN 1; C-14,442). Within six months, the international debate had begun; Argentina, on June 26, 1970, submitted a set of draft principles toward an agreement on remote sensing (UN 2). This draft highlighted the crucial issues of the right to collect and dissiminate

resource information (UN 2, Art. 5,6; C-14,443). It also suggested that any resource information data banks should be available to all countries with special attention to the needs of developing countries. It further emphasized the sovereign rights of states, especially their exclusive rights over natural resources, which were to be governed solely by national laws and regulations (C-9c, 27). While at the time of its submission, there seemed little hope of its proposals being agreed upon, it provided the impetus to begin working towards a treaty. The debate which followed took place in the context of third world calls for a New International Order and continued East-West conflict.

In the meeting of the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) the various strategies of the countries debating the initial stages of remote sensing issues as raised by Argentina began to emerge. They centered around two primary thrusts. The one, an "operational" thrust emphasized the development of the technology with attendent legal regulations to be developed following the proof of technology. The representative of the United Kingdom stated his countries belief (and the U.S. position as well) in this approach: "We should now await decisions concerning technical regulations whic' will govern remote sensing by satellite before proceeding with consideration of associated political and cultural problems" (UN 3, pv.86, 9/70, pg. 46). In this vein the U.S. also issued an open invitation to foreign experimentors and through NASA offered international workshops to acquaint foreign users with the technology and its application potential. At the same time another position was developing--an organizational approach, pushed by the Swedes and the

Italians (see a/ac.105/c.1/Sr.2). The Swedish representative suggested that the UN "should ultimately aim at a far-reaching internationalization of earth resources satellites within the framework of the UN ... only in that way can we hope to overcome national sensitivities concerning the use of data-collecting earth resources satellites; and only in that way can we hope to safeguard the principles of non-discrimination and free access to data, which should be the basis for our deliberations on this topic" (pv. 86, UN 3, 9/20, pg. 72). Here then a position develops which suggests that the U.S. policy of open dissemination and equal access to the data is favorable, but rather than let the technology evolve an organization ought to be se, up to guarantee the "internationalization" of the data, and the protection of states rights. While the USSR was largely silent in the 1970 meeting, the position of the UAR foreshadowed the Soviet position which would serve as the counterpoint to the US and UK position. The UAR representative stated in 1970 that "in our view, the legal aspect of earth resource survey saellites should, indeed, be considered in the light of the principle of the sovereignty of state over their natural resources" (pv.86, pg. 101). While this position was not as legalistic as the Soviet position would be, it suggested the basis of the third position to develop in the UN--that of the primacy of state sovereignty which would lead to desires for legal regulation and a prior consent regime.

In fact the Soviet position was not far behind. At the 1971 meetings of the UNCOPUOS the UN representative from the Soviet Union stated that "... in addition to technical aspects," remote sensing of the earth resources "... gives rise to many other political and economic problems. It

involves above all, the matter of respect for the sovereign rights of
states. A state has the exclusive right to do what it deems fit with its
own natural resources and with information regarding them ... it is obvious
that the only lasting basis possible for the application of artificial earth
stellites to remotely survey the earth's resources must be grounded in large
scale international cooperation; its foundation must be strict legal
regulation of activities in space" (UN 3, pv. 100, Sept. 1-10, 972, p. 62).
Note that not only is state sovereignty over its own natural resources
emphasized, but also the sovereignty of a State over information about those
resources. This is taken a step forward to explicitly suggest a legalistic
approach to controlling the technology and its application. The dichotomy
of beliefs between sovereignty over information and an open dissemination
policy and their attendent approaches in the UN--that of a
legalistic/regulatory approach and an operational approach were now set in
place. A middle line of thought, represented by the Swedish among others,
was supported in 1971 by the French. They seemed to believe that access to
remote sensing systems should be kept as free as possible while preserving
the "maximum sovereignty for each country concerned" (UN 3, pv. 100,
9/1-10/72, pg. 29).

Meanwhile, the U.S. continued to report on the progress of its first
satellite, launched in July 1972. "As of mid-August [1971], 104
experimentors from 32 countries and 3 international organizations had
responded to" the U.S. open invitation to experimentors. Interest in the
program was clearly beginning to expand.

In 1972, at the meetings of the UNCOPUOS, opposing positions seemed to harden. The Soviets reaffirmed their position strongly: the legal problems of remote sensing satellites "arise from the absolute and exclusive right of states to control their own natural resources and information about those resources" (UN 3, pv. 111, 9/72, p. 27). "It is quite obvious that the only sound basis for scientific cooperation in the use of satellites for remote sensing of earth resources is the international legal regulation[3] of activities of states in the field" (UN 3, pv. 111, 9/72, p. 27). This position was taken the next step by the Egyptian delegate. "To conform with the principle of sovereignty, the consent of the state in question is indispensible before the survey of its national resources by remote sensing is started" (UN 3, pv. 115, 9/72, 7). This position was strongly supported by the Argentinian delegate (UN 3, pv. 113, 9/72, 56). The push for some sort of legal regulation also seemed to be accepted fully by the Swedish delegation which from the outset had "stressed the organizational and legal aspects of remote sensing activities, namely the questions of who should manage the technology and who should exploit its results." And questioning their own previous policy of open dissemination and equal access, they suggested that "it is a debatable question whether openness as such also means that all have the same chance to utilitze the results of the technology. The contrary may well be true, especially for countries with a weak technological base and limited abilities to access and make use of

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[3] International legal regulation refers to efforts to guide the development and application of remote sensing technology using a legally binding treaty or principles.

information" (UN 3, pv. 111, 9/72, p. 46). The Swedes therefore tied the issue of technical assistance to the U.S. policy of open dissemination. They believed in open dissemination, as suggested earlier, but felt that an organizational/legal approach was the best way to achieve that end. This contrasts with the U.S. approach as this approach was summed by the delegate of the UK. He suggested that "we need not be in too much of a hurry to examine the legal and organizational aspects of remote sensing. To do so might result in our wasting time over problems which in practice will turn out either to be nonexistent or very different from what we now imagine" (pv. 114, 33). In other words let the technology develop and let it govern the legal and organizational forms that develop. This position was strongly rebuffed by the Italians. Their delegate expressed surprise over the U.S. and UK position. He reminded the committee of GA Resolution 2776 (XXVI) that stated that the working group on remote sensing would "make recommendations for possible development, provision and operation of remote sensing data collection and utilization systems in the UN or other international framework, taking into account the economic, social and legal implications for the international community that might arise as a result of selecting any particular system." This overview of the competing perspectives set the tone for the UN efforts to develop legal draft principles for remote sensing satellite. The effort to draft legal principles was in some ways doomed to ultimate failure in that the U.S. amongst others, did not think they were necessary and pursued an operational strategy in any case.

On April 18, 1973 the Soviet Union submitted "Model Draft Principles
Governing the Use of Space Technology by states for the Study of Earth
Resources" (A/AC.105/L.88). This Soviet draft, meant to signal the Soviet
position, reaffirmed the right of state sovereignty over its own natural
resources and suggested that any information obtained about a state should
be transmitted to that state without such information being made available
to third countries (C-9c,276; C-14,445). This is a position which the
Soviets have largely adhered to, with minor modifications, until the
present. In May, the French submitted "Draft Principle Governing Remote
Sensing from Outer Space (UN 5). This draft also reaffirmed a states right
to permanent soveriegnty over its own resources. In addition, any state
being sensed was to be informed of that fact and it suggestd that
documentation on one country could not be transmitted to a third party
without that country's consent (C-9c, 276). In early February 1974, Brazil
joined the debate, submitting a "Treaty on Remote Sensig of Natural
Resources by Satellites" (UN 6). This treaty supports a prior consent
regime for both sensing and distribution of the data (UN 6, Art 3,7); it
supports participation by a sensed state in all sensing activities going on
over their country (UN 6, crt 7,8); and implores the technologically
advanced countries to aid the less developed countries in the use of this
new technology (UN 6, crt 9; C-14,446; C-9c,277). The Brazilian and
Argentinian drafts seemed to estblish the issue of legal overflight and to
insure prior consent from a country before pictures are taken (C-37,10).
In essence this broke the issues into two parts--data acquisition and data

dissemination. Data acquisition never amounted to much of an issue--it was largely a moot point, and seemed to be covered under the Outer Space Treaty. The real issue focused on what happens to the data once it is obtained. In fact, a joint Soviet-French submission (UN 19) on May 27, 1974 largely ignored the data acquisition argument pushed by the developing countries and focused on what has become the center of a restricted dissemination regime. It suggsts that documentation resulting from remote sensing activiti3s may not be communicated to a third party (UN 19, art 5), except in the case of natural disasters and phenomena which can be detrimental to the environment in general (UN 19, art 5c; C-13,61-63). It reinforces the principal of national sovereignty (UN 19, art 2) and the "right of an over orbited nation to participate in experiments should it so desire (UN 19, art 5). The emphasis is clearly on restricted dissemination of the data and the full participation of sensed states. It does not explicitly state that a state has rights to data obtained about its resources. A joint Brazilian/Argentina effort submitted in October 1974, "Treaty on Remote Sensing of Natural Resources by Means of Space Technology" (UN 20), adds to the Soviet/French principles. It agrees that all sensed states have the right to participate in all sensing activities and the states have an exclusive right to exploit their own natural resources (C-14,449; C-13,61-63). But it adds that states have a right to access to all information obtained through sensing activities, prior to that data being disseminated to a third party and that states have a right to technical asistance (C-14,449; C-13,61-63). This treaty was supported by

Mexico, Chile and Venezuala.   In essence, developing countries were worried about being left behind in an open dissemination regime because without the technology and without technical expertise remote sensing data is useless. Hence, they pushed hard for technical assistance--and technology transfer (C-2i, 155) within a closed or restricted dissemination regime.

The push for a restricted or prior consent regime was not immediately met with a counter proposal.   In fact, the sharpest debate arose over the question of legal aspects of remote sensing.   Some delegations took the view that there was a need for the elaboration of principles to govern the activities of states engaged in remote sensing.   Other delegations do "not share this view" (UN 3, pv. 123, 6/28/73, p. 22).

The U.S. agreed that principles were not necessary.   The Austrians condemned the overly legalistic approach which postulate legal problems before they have been well defined" (UN 3, pv. 132, 7/2/74, p. 32).   At the same time, a middle position--one pushing for continued work on technical questions as well as legal questions--came to the fore.   The Swedish delegate suggested that organizational and legal studies should move along together (UN 3, pv. 136, 7/5/74, p. 71-72).   The Japanese, Brazilians, British, French and Indians all agreed on this view (UN 3, pv. 136, 7/5/74).   Finally, a thrust to pursue organizational aspects drew support. The Swedes proposed to study organizational possibilities stating that if applications were carried out "in full awareness of the political and legal issues involved, some of the problems might be solved automatically as the organizational structure was put into place" (UN 4/SR 123, 1974, p. 55). The Indians followed the Swedes, stating that while many legal questions

must be worked out, there was no reason not to discuss what steps to immediately take (UN 4, SR 123, 1974). The Australian delegate thought that a study of the implications of the various organizational possibilities was a good idea because it would then put the discussion of legal aspects in a practical and realistic context. (UN 4, SR 123, 1974, p. 65).

This idea was rebuffed by third world and Eastern bloc countries. The delegate of Brazil suggested that a study of organizational aspects "might set in motion an organizational process which would prejudge the study of the legal questions related to remote sensing. ..." (UN 4, SR. 124, 1974, p. 53). These two positions illustrated two trends which had emerged.

The first trend focused on the issue of data dissemination. One side accepted the principle of free collection and distribution of data; and the other favored a more strictly controlled collection and distribution, possibly subject to the agreement of sensed states.

That was the real crux of the problem. In order to meet the concerns of those who wished to see such activities regulated in such a manner as to protect the rights of sensed states, some new technologies would undoubtably have to be devised, and at present there was some uncertainty as to whether that was possible. Conversely in order to satisfy those who would prefer remote sensing activities to develop in accordance with the principles applied thus far, some new legal principles would have to be adopted, and it was by no means certain that all states were prepared to change their laws to accommodate such a policy (UN 4/SR 123, 1974, p. 51).

The second trend focused on the approach to be taken by the U.N. The first would "give priority to the organizational aspects, in order to facilitate the solution of the legal problems, and the second would settle legal questions first so that the organizational problems could be solved more easily" (UN 4/SR. 123, 1974, p. 51).

In February 1975 the U.S. finally joined the debate. Bound in some sense to support the legitimacy of the UN process, but opposed to any notion of restricted dissemination, the U.S. submitted a working paper stating its position (UN 7). This document affirms a U.S. open data dissemination policy; but has no discussion of sovereignty questions or prior consent regimes. It suggests that nations are welcome to participate in U.S. training programs (C-26,26-30). The U.S. did not see any necessity for a treaty in that the Outer Space Treaty covered remote sensing. This position did not recognize the impact of dissemination of data on natural resources and a state's national sovereignty.

On reviewing the remote sensing working group documents it is clear that developing countries regarded the U.S. practice of open dissemination of their natural resource information as a direct challenge to their sovereign power over their own resources (C-37,216). A part of the international debate then, turns on whether an interpretation of the Outer Space Treaty would respect sovereignty over natural resource information and thereby limit U.S. freedom to disseminate information without the consent of the nations concerned" (C-13,47,48), or whether this position neglects "the fact that exploitation cannot really take place without the knowledge and effective cooperation of the country in which the resources lie" (Hosenball

Speech, C-13,50). The question is clear. Is information about resources a national resource? Does the principal of state sovereignty extend to such information? These questions tie into the complex problem of understanding the impact of natural resources information on trade and resource exploration negotiations.

Out of this international debate seven arenas of contention can be discerned. These include 1) questions over international and/or regional cooperation for peaceful purposes; 2) questions over sovereignty--both over resources and information; 3) questions over state responsibility for remote sensing activities regardless of whether it is a government or private sector enterprise; 4) the question of access to data--should here be open dissemination or prior consent; 5) authorization to use data--should it be given by the sensed state; 6) what to do when disputes occur; and 7) what is the role of the UN to be? (C-2b,26-30; C-37,10).

To briefly recapitulate: through the late 60's and early 70's, domestic political activity was focused on the bureaucratic machinations of launching the first ERTS satellite. The key issues focused on the technology to be flown, whether or not ERTS would be a cost effective tool and the potential international sensitivities to high quality, easily available remote sensing data. International political activity during the early 70s focused on efforts to develop some sort of international regime to guide the dissemination of data, the use of the data, the availability of technical assistance, and the role of the UN. As ERTS-1, later renamed Landsat-1, began to collect data it intensified the debate in the UN. As the U.S. system continued to scan the world, it seemed to make much of the

international debate into idle rhetoric. However, the debate was justified

in that the U.S. system was considered experimental and used experimental

radio frequencies. When the domestic debate shifted to the development of

an operational system that would use other frequencies, domestic and

international issues were joined, irrevocably linked in the policymaking

process.

Domestic Politics - An Operational System?

In 1974, two bills were introduced in the U.S. Congress - S.2350, the

"Earth Resources Survey Act of 1974" and S.3484, the "Earth Resources

Observation Administration"--to initiate an operational earth resources

remote sensing program in either NASA (S.2350) or The Department of the

Interior (S.3484). The debate over these bills focused on three things.

First, the worth and potential of Landsat data. Here many university

experts were brought in to counter the OMB's charges that little rigorous

analysis had been done to understand the use and worth of such data (C-9,

C-11). Second, the debate focused on which agency should house the

operational Landsat program, NASA or Interior. Proponents for a

user-oriented approach favored Interior, those with a more interest in

advancing the technology and technological expertise favored NASA. Finally,

the domestic political question of an operational system was brought

together with the international debate. Dr. Franco Fiorco, then chairman of

the UN working group on remote sensing of the earth by satellite, stated

that while the international community was generally in agreement "on the

need of continuity in the supply of remote sensing data" it was experiencing

wide "disagreement on the U.S. policy of 'free dissemination' of the data acquired from space" (C-11, p. 226). Further, "many countries, and amongst them some which are already beneficiaries of such a policy, have clearly expressed their views that their acceptance of such policy in today's state doesn't imply at all that they favor it for future operational systems ..." (C-11, p. 226]. Moreover the Department of State was firmly against enacting legislation to create an operational system. The U.S. had repeated in the UN that no plan existed for an operational system. Therefore the data dissemination regime applied largely to the experimental system. A Department of State spokesman stated that "... we have consistently said that our present data dissemination policy applies specifically to experimental systems. We will have to face the specific question of whether or not our dissemination policy will also apply to an operational system ..." (C-9,243), and continued that "if the U.S. were to declare an operational system the international community might conclude that the U.S. was prejudging the proper means of using this technology while international arrangements ... were still under consideration" (C-9, 284). To go a step further, U.S. representatives had stated that "if a consensus should develop in the UN ... expressing the view that the U.S. ought not to permit the dissemination of country B's data to country C" the U.S. would "consider ceasing that dissemination" (C-2f; C-2i).

The debate here was clear. Remote sensing satellites are inherently international: Could the US develop an operational system nationally without some sort of operational international system? And if it is an international system by nature, does that imply that the question of whether

to call it experimental or operational was not really the question? The
real question was whether or not they (the UN countries) are going to play
an influential role in determining the worldwide use of the system (C-9,
293).

Several U.S. policy analysts have noted the importance of balancing
domestic and foreign policy considerations (Desther, Willard). In this
case, the domestic goals focused primarily on meeting the resource
information and environmental monitoring needs of the federal, state and
local governments. This pushed the U.S. toward an operational system.
U.S. foreign policy considerations included developing better international
relations with other nations through application of space technology to
their national problems; strengthening the UN and other international
organizations by including them; "minimizing the potential international
administrative, legal, regulatory, economic and political difficulties
arising from an operational earth resources sensing system; by early
involvement of individual national and international organizations" toward
the smooth transition from an experimental to an operational system; and the
removal of a contentious issue from world politics by opening up the program
to international participation (C-5,59; C-35). Responding to these foreign
policy objectives meant that "despite increasing foreign use and interest in
Landsat an emphasis on Landsat as an experimental rather than an operational
tool is recommended by foreign policy considerations" (C-9,282-83).

Up to this point private sector interests were not strongly engaged in
the debate. But already domestic goals and bureaucratic politics had been
joined to foreign policy considerations stemming from the international
debate taking place in the U.N.

The U.N. Debate; Part II: Compromise and Stall

During the early 1970s the U.S. proceeded to build its international
constituency. As Landsat-1 and then Landsat-2 (launched in January 1975)
continued to monitor the earth, the U.S.--in an effort to develop better
global coverage and in the interests of international cooperation and
acceptance--began to spread ground receiving stations around the globe.
Each station is made available under a bi-lateral agreement which provides
for making all data collected by a foreign ground station available on a
non-discriminatory basis to all users (C-8a,13). Such agreements were put
into effect with Canada in 1971 and again in March 1975; Italy in May 1974;
Zaire in January 1975; Chile in September 1975; Argentina in 1975; and
Brazil in May 1976. While many bilateral agreements have been signed,
including one with the Peoples Republic of China (NY Times, a-16, 1/9/80),
perhaps the most important were with Argentina and Brazil. These two
countries "reversed their protectionist position and adopted the U.S. policy
of 'open data' agreeing to permit "unrestricted public availability of all
earth resources satellite data of areas within range of the (respective)
ground station" (C-13,441;C-14,60). [MOU-Brazilian Commission for Space
Activities and the U.S. NASA, 5/14/76 and MOU-Argentina, etc.] It is not
surprising then that Brazil, Chile and Argentina--the vanguard of the
developing world in the U.N. debate are no longer "dogmatic in asserting
their sovereign rights with respect to remotely sensed data" (C-12,10).
What had happened in the U.N. debate was that Brazil and Argentina, both of

which had been advocates of some sort of prior consent and restrictive

dissemination regime, began to pursue principles instead of such a treaty.*

At the same time Mexico, which endorsed the Latin American Draft

Treaty, exprssed disappointment that the committee had abandoned the drive

for a draft treaty. It is written into the constitution of Mexico that the

'state' has the right to dispose of all data relating to its natural

resources, and has rights to all studies and expoloration regarding natural

resources. In order to meet their constitutional requirement the U.S. may

offer Mexico all data on its territory, thereby (hopefully) reversing

Mexico's present position (C-13, p. 66).

The U.N. debate had changed complexion. It began with a debate over

the U.S policy of free overflight and open data dissemination. The prior

issue had never amounted to much. The second had been at the crux of the

debate. A consent regime developed, originally supported by the Soviet

Union, France, Canada, Sweden, Brazil, and Argentina (C-8a, 30-31).

However, the third world bloc retreated from this position. Sweden, which

now has a ground station has withdrawn its support (C-8a,30,31). And

Canada, in the 1976 meeting of the legal subcommittee, endorsed the policy

of open dissemination of data. However, Canada "proposed that processed

information or analysis of imagery of a sensed state should be restricted to

access by the sensed state" (C-13,59, UN 8). This was an effort to

compromise between the open dissemination policy and the restricted regime

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* A treaty would be legally binding international agreement; principles are
non-binding guidelines. They have also become less dogmatic about a
restricted dissemination regime (C-13, pp. 56-57).

idea--but would have been very difficult to enforce. Canada also signed a five year agreement with the U.S. in 1976 which, in part, guaranteed open, non-discriminatory access to data taken by Canadian ground stations.

In March 1976, in the science and technology subcommittee, the Soviets submitted a working paper proposing a breakdown of the data into 'global' and 'local' data; global data to be freely disseminated, local data to be distributed subject to internationally established legal principles (UN 9;C-13,71). This paper, introducing the concept of a need for a resolution cutoff point contained no definition of what that cutoff point should be. It was to this question, in fact, that the debate now turned. The Soviets (and the Eastern Bloc) found themselves suddenly isolated. And a West German attempt at draft principles seemed to reinforce that isolation (UN 10). This set of principles was largely a compromise position, emphasizing the promotion of economic and social progress in developing countries (UN 10, article 6), emphasing the right of the sensed state to participate in the estimates of the sensing state (UN 10, article 6), and recognized the impracticality of a prior consent regime. But it did not discuss soveriegnty (C-14,451,452). In fact the document asserted the "American point of view that the issue of sovereignty is not germane to this type of technology" (C-14,452). However, it did little to molify the fears of the Soviet Union about military exploitation of the data and the fear that the U.S. might gain an important economic and/or diplomatic advantage.

In May 1976 on the heels of the German document, Mongolia submitted a draft principle parroting the Soviet position on sovereignty over information and on a restricted dissemination regime (UN 11; C-14,453).

This drew a sharp response from the delegte of the United Kingdom, who insisted that sovereignty over natural resources did not extend to soveriegnty over information concerning those resources. This was in line with the standard western position on the free flow of information throughout the world (UN 12, sr. 263, 5/28/76, p. 7).

Also in May of 1976, a new development in the negotiations occurred. India submitted a note confirming its intention to build its own satellite and regional ground station, with the launch being done by the Soviet Union. Because both the Soviet Union and India are opposed to an open dissemination regime, this had the looks of starting up a competitive remote sensing system. By inviting U.N. sponsorship of the ground station they hoped to gain U.N. endorsement of a limited dissemination system. It seemed that because agreement was beyond reach, international competition would now begin (C-13,71-72).

In any case, by the end of the working session in May 1976, the U.N. working group on remote sensing met and formulated the text of five draft principles which were based on common elements of earlier draft treaties and principles. These five included:

1. that remote sensing be carried out for the benefit of all mankind, with special attention to the needs of the developing countries;

2. that remote sensing be carried out with respect for international law;

3. that international cooperation was essential and to maximize benefits should regional facilities ought to be considered.

4. that remote sensing should be used to protect the environment; and

5.   that states participating in remote sensing shall make technical
     assistance available to those wishing it, on mutually acceptable
     terms. (UN 13, C-13,143; C-14,454).

However, no agreement could be reached on data and information
distribution policies. This was left for future work (UN 21, Annex
III,pp. 4-5). These 'agreed upon' principles did little to settle the
question of open dissemination and the sovereignty of the sensed state over
information pertaining to its natural resources.

On the other hand, the technical assistance principle is critical.
"The limiting factor ... in the use of this technology by developing
countries is the underdevelopment of their own information systems,
untrained people, and uninformed leaders ..." (C-17,86). In essence, this
training issue "seriously calls into question the twin premises of U.S.
policy that maximum dissemination assures maximum benefit and that equal
access guarantees that no one state will benefit to the disadvantage of
another" (C-37,201). And is it really an open dissemination system at all?
"Embedded within the complex technological realities of the entire remote
sensing operation is the fact that the multispectral data obtained from the
orbiting satellites are virtually useless to the untrained interpreter
lacking the proper computer hardware and facilities" (C-37,199). In fact,
the U.S. has developed a largely global system in line with its own policies
and desires. What seems to be the mode of obtaining acceptance of that
system is the trade-off of technical aid and international participation.
For those already using the system, the lack of a U.S. commitment to an
operational system kept them from using it more (C-17,91).

A third phase in the 'international' debate began in February 1977. The Soviet Union submitted a working paper regarding cooperation between the Soviets and other states in remote sensing (UN 14). The Soviets wished to affirm their "willingness to make available the achievements of Soviet Space Science and Technology" (UN 4). The Soviets emphasized their desire to cooperate with other states by making all data obtained by remote sensing surveys available to them in the spirit of "equality in accordance with international law with due regard to the unalienable right of states to exercise permanent sovereignty over their natural resources including the right to dispose of their natural resources and of information concerning them" (UN 14). They further guaranteed restricted dissemination of data with resolution better than 50 meters. So called global data, with resolution greater than 50 meters had no guarantees on dissemination. And nothing is said about the 'rights' of non-cooperating states (C-14,454-56). This submission seem to signal the Soviet intention to establish a global system competitive with the U.S., and a Soviet belief that little would be accomplished in the U.N. to establish acceptable principles for guiding remote sensing activities. As such, the international debate moved, in part, from the realm of multi-lateral negotiations to the realm of competition amongst national sytems, and the possibility for developing a global regime was largely cragmented.

The Domestic Debate--Part III: Enter the Private Sector

On February 7, 1977, Senator Ford introduced the "Earth Resources and Environmental Systems Act of 1977" (S.657). This bill would have directed NASA to continue R&D and to establish the space segment of the system while

the Interior Department established the data handling segment of the

system. In this bill, state and local government needs were to be taken

into account and the Director of the Office of Science and Technology Policy

was to "determine the benefits of participation or management by the private

sector in providing the products and services for the system ..." (S.657,

pg.8). A new wrinkle had been added to the bill--the possibility of private

sector involvement in the operation of the system--if not its ownership. In

the same year, President Carter reaffirmed a U.S. commitment to

international cooperation in remote sensing--offering Landsat technology as

a component of U.S. foreign policy in a speech to the Organization of

American States (C-18,9). The establishment of an operational system,

again, was the focus of the domestic debate in 1977. However, it now took

on, in part, distinctly international importance. The chairman of the

UNCOPOUS (Ambassador Jankowitsch) testified that in fact "there is a growing

consensus in the international community on the need for a global

operational system of remote sensing satellite guaranteeing to users a

continuity of data within a specific time frame" (C-18,467). However, this

does not mean that the system can, necessarily, be set up on U.S. terms. He

further commented that the U.S. program is seen as experimental and as such

complaints about U.S. data dissemination policies had lessened. However, he

warned that "there may well be a different situation when remote sensing

systems become operational and requests for data are on a regular basis"

(C-18,469). While much of the demand for a restricted dissemination regime

seemed to have dissolved, the "... establishment of a U.S. program which

does not provide for practical and economical opportunities for continued

international participation" might well reinvigorate demands for international restrictions (C-18,518). As translated into U.S. policy and plans, "other nations must have a voice in the structuring of the global earth resource information systems that may be developed ultimately" (C-18,9). This points to a major point of question in the debate over an operational system and the extent of international involvement. "It can be argued that remote sensing technology and information about earth resources are valuable assets which should be closely controlled to protect the technological lead and economic power of the U.S." However, "it can also be argued that an international system would best serve the interests of the U.S. on grounds that benefits accruing to other countries would result in international goodwill which would more than offset short range U.S. technological and economic losses" (C-24,18). In either case, while technology transfer and the development of foreign expertise has mitigated international concern over Landsat, and while international participation in the U.S. program has created dependence on the U.S. program, there is also a presumption in the international community that the U.S. program will continue (C-18,518). As such, "any decision by the U.S. to establish an operational resource sensing system will inevitably have international consequences" (C-17,125). To proceed with an operational system, particularly a domestic system, "would have significant influences on U.S. relations with many foreign contries" and "should take fully into account both the international cooperative programs" already developed and the role of the U.S. system in the interest of an nternational system which the U.S. or other countries might develop in the future (C-17,125; C-18,517).

Whatever system is developed, it must be remembered that fears of economic exploitation have been dealt with largely "by providing and encouraging the development of expertise in many areas of the world as well as providing open access to the data" (C-18,510,519) and that U.S. diplomatic efforts will be hurt by a protective U.S. policy. In a sense, "the integrity of the U.S. commitment to assisting others in their own struggles for economic development" is at stake (C-18,519). Put in these terms the issue of an operational system--what had been a domestic policy question to start with--is heavily constrained or impeded by international pressures as they are translated into foreign policy considerations. In some sense the U.S. is tied by its previous policies encouraging technological aid and widespred participation. These policies were successful in defusing initial international sensitivity. To change those policies in 1977 would, according to U.N. and Department of State representatives, have reinvigorated international concern. While private sector considerations challenged this policy NASA took "the position that at least the initial receipt and preliminary processing and distribution of data in an operational system should be handled by the U.S. government to ensure equal treatment of all Landsat users" (C-24,18). Hence the debate began to take shape on where and who should operate the operational system. From an international viewpoint, the responsibility clearly resides with the government.

State governments, in general, heartily agreed with this appraisal. In fact they allied with it. "The Public Service aspects of this particular enterprise and the sensitivity of international issues upon it make

government control and regulation its natural path" (C-17,65). In fact on

several issues "public sector" and foreign policy considerations were in

consonance. One such issue was that of continuity. OMB had argued that

Landsat C[5] was not critical to continuation of the program while the

international community insisted that "continuity is vital to increasing the

demands of users from the developing world" and that, as mentioned above--it

seemed tacitly understood that the U.S. program would continue. To back out

on a U.S. program which had generated a great deal of foreign investment

would not aid U.S. diplomatic or foreign policy efforts. The same is true

of state and local governments--who are concerned about continuity before

making further investments in Landsat equipment (C-17,126; C-13,281).

Another issue that arose was the matter of pricing and this ties into

the question of open dissemination. If one must be tained and rich to buy

the data then freedom of information becomes freedom of the "well to do."

Thus, high price would discriminate against poorer developing countries and

probably rekindle restricted regime proposals (C-37,202). State and local

governments, the public service community, also did "not want to see the

inclusion of private industry causing product prices to rise to unreasonable

levels" (C-17,287) as price increases "must be weighed against the limited

resources of local and state agency data uses" (C-18,107). And like the

international community, state and local users are insistent on a role in

the decision making process (C-18,107). However, over the issue of

dissemination, state and local governments favor open dissemination with no

restrictions whatsoever (C-17,207).

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[5] The third satellite in the US Landsat series. It eventually flew in March
1978.

It is not immediately clear why a private sector initiative should have
gained mcmentum in an atmosphere in which government control is favored.
However, this is an atmosphere, as well, of tight budget constraints and a
sense of declining U.S. technological productivity and superiority. With
the success and lessons learned from the satellite communications industry,
it was generally thought that this system provided an opportunity to develop
a U.S. industry which would be a world leader and provide a general example
of government-business cooperation in bringing technology to the
marketplace. However, the desire for private sector ownership contradicts
on-going U.S. practice, and creates splits between the bureaucratic agencies
involved and the other groups participating in the program. It is the
demands of the private sector, and the contradictions and conflicts they
produce. to which we now turn.

Private Sector Concerns

The U.S. private sector interests must be broken down into three
groups; those companies which are satellite and system manufacturers, the
value-added services industry and the private sector user community.
Generally they are in agreement on Landsat policy issues. I will largely
focus on the manufacturers, pointing to disagreements amongst them as I
proceed.

Private sector interest in Landsat had always been high, from the late
60s when fifteen companies submitted proposals to the USGS to design an
Interior Department satellite. At the same time a mineral and oil
exploration company had discussed a proposal for owning and operating a

satel,ite for remote sensing, but the government had rebuffed these

overtures.   However conditions have changed and this section on private

sector interests becomes a discussion of the conditions, in the late 70's,

under which the private sector would assume an ownership role; conditions

for both the private sector and the government.

The private sector strongly desires the system to be implemented on an

international scale, with a policy of "open" dissemination, thereby assuring

the largest possible market (C-17,76). But their concept of open

dissemination needs clarification. While they were concerned "that a legal

regime would be adopted to govern the acquisition use, and distribution of

data which would unduly and unnecessarily limit ... the market for data

products and services" (C-17,225) they further argued that "it does not seem

necessary ... at this stage to guarantee by law that foreign users shali

have completely equal access to all products of the systems" including

summaries and conclusions from "reduced" data (C-17,239). To avoid

international difficulties, and under the assumption that the institutional

framework for establishment of an operational system by the U.S. can proceed

prior to the resolution of all questions involving international

participation (C-18,189) the private sector suggested that a domestic system

should be established first, prior to the development of an international

system--but should allow international participation.

> The system obviously has strong international overtones, but it should
>
> proceed as a U.S. National system initiative because of the tremendous
>
> difficulty in organizing any initiative involving the multitude of
>
> nations which have an interest, each with differing capabilities and
>
> objectives. (C-20,373 in C-18)

Data ought to be distributed subject to international rules but "a

requirement to place value-added data products in the public domain may be

inappropriate since a large portion of the market for products and services

would be eliminated" (C-18,640).   In addition,

> U.S. businessmen may be seriously offended if they find that a program
>
> paid for by their tax dollars puts them in a disadvantageous position
>
> vis-a-vis foreign competitors as a result of suboptimal arrangements
>
> for processing and distributing the data.   (C-18,213).

More to the point, if the desires of those countries who were and are in

favor of a restricted dissemination regime were met, it would render the job

of making Earth Fesources Remote Sensing financially viable more challenging

than it already is (C-12,11). However, the private sector notion of open and

the international community's notion of open are two very different things;

"any effort to make a subset of the data proprietory would inevitably lead

to strong opposition from the sensed countries" (C-12,12).

The private sector believed that the government must stay in the remote

sensing business until a market existed and the investment risk became

tolerable.   In fact they wanted (and still do want) the government (1) to

guarantee a market by satisfying its own data requirements through purchase

from the private sector (C-18,70); (2) to continue R&D (C-17,218); and (3)

to assure users on data continuity (C-20,285),(C-17,224) and the

availability of data in a timely manner (C-17,244).   The bigge.: step the

government should take, according to private sector interests, is to

eliminate direct competition with the private sector.   "Government should

not be involved in providing analysis, technology transfer, or training to

any organization not directly involved in their projects or programs"
(C-18,514). In particular when the government stops competing in the supply
of services, private sector interest is likely to increase (C-18,170). Here
the value-added services industry was adamant, particularly in regards to
eliminating part of the Department of Interior's EROS program. In
testimony, one value-added services industry member suggested that he had
"lost directly very substantial sales from private industry where we have a
capability which is at least as good as that capability now being provided
by Sioux Falls" (home of EROS)(C-18,230). Paradoxically, therefore, the
private sector wanted the government to aggregate the market (C-18,208)
while getting out of the services and technology transfer business. However
state and local governments insisted on the need for a Federal Technology
Transfer program (to be further discussed shortly) and so too with developng
countries and the foreign market. In fact, both the state and local
government and the international market are likely to expand over the years
and increase their share of the total market.

To do this, however, some technology transfer will be required. Some
analysts argue that such technology transfer is a small price to pay for the
political and economic benefits which would accrue to the U.S. (C-12,12).

In an effort, as stated earlier, to maintain the widest possible
market, international control was seen to be totally infeasible as all
policy questions would hopelessly bog down (C-17,213). This raises another
issue, however, because "it is unavoidable that a system for civil remote
sensing from space be in some sense international" and that "there will
continue to be involvement in one form or another by other countries ..."

(C-7,22). This raises the question cf international participatio:1. In
fact, giving developing countries an input into the decisionmakin3 process
would grant them participation and hopefully result in trong support for
the system. Failure to gain this support could result in business being
transferred from the U.S. system to other competing systems (C-12,11-12).
While this 3ets a bit ahead of the story, it is important to remember that
this technology has a special problem (which communications satellites
didn't)--that is that users must be developed along the way, they do not
already exist (C-17,87). This suggests that user input could be important
to their participation as buyers. And if anyone had hopes of establishing
an international system, including international participation, moving the
system to "the private sector is probably just not compatible with the
notion of a more international approach ..." (C-17,90).

In sum the question of private sector involvement raised questions
about the possibilities of international involvement in system management,
government involvement in technology transfer and data processing, about
control over U.S. foreign policy and most importantly about the type of data
dissemination system to be adopted by the U.S. and the international system.

At this stage, all of the major actors were visable. The political
conditions stemming from the interests of these actors began to reflect the
compexities of a global technology. They involved, according to one
government study,

1.   means for effective participation by other nations in design,
     management and cost-sharing of the system;

2.   arrangements that demonstrate and support continued U.S.
     technological and commercial leadership;

3.   technological restraint to avoid international sensitivities on resolution;

4.   arrangements guarnteeing the rights of remote sensing and open dissemination;

5.   provision of a return on U.S. investment, and possible privte sector participation;

6.   means for effective U.S. influence in whatever international system develops; and

7.   defusing the image of U.S. exploitation of technology and avoiding the continued appearance of developing country technological dependence. (C-7,23).

These are clearly not completely complementary. And in fact, the addition of a much firmer state and local government position, provides a sharp contrast to private sector interests. Domestically, the issues now crystalized.

While the federal government and the private sector expressed concern about potential markets, state and local governments tended to couch the issues as constraints on their use of Landsat--i.e., the constraints on developing state and local markets. They pointed to the following issues:

-    lack of a federal commitment to an on-going system;

-    inadequate technology transfer activities;

-    ill-defined federal agency responsibilities;

-    lack of involvement in Landsat decisionmaking;

-    lack of federal understanding of state governments operational nature

-    data problems, including timeliness, resolution and preprocessing (C-26,17)

Their prescriptions, however, differed widely from those of private

sector interests, in some cases, and were more similar to those of the

international community, in most cases. Along with the private sector and

the international community, state and local governments realized the need

for an operational system. "As long as the Landsat program remains

experimental rather than operational, state governments will hesitate to

invest in the development of trechniques, staff and equipment to make full

use of ... Landsats potential" (C-26,18). This is one of the catches to

satisfying OMB's requirements for successful demonstration of cost-benefit

ratios. For, providing quantitative results requires successful

demonstration, but users are unlikely to make the investment necessary to

make operational demonstrations effective without some Federal commitment

insuring that the investment doesn't go to waste (C-7,10).

On technology transfer, however, where the private sector wants the

government to allow it to do whatever technology transfer is required, state

and local governments are in sharp opposition. "A major constraint to the

state and local government use of Landsat has been the lack of coordinated,

well structured, and adequately supported technology transfer programs"

(C-26,19). Such a program must, according to state and local interests,

include a clear mandate for undertaking staff training, information

dissemination about Landsat, technical assistance and consultation,

demonstration projects, and software development and dissemination

(C-26,41).

On the question of participation in system decisions, whereas the

private sector has high input, state and local governments again agree with

the international community in that "this interesting new technology has not

been used regularly by non-federal interests and agencies because they had

no input in the design capabilities of the satellites" (C-26,35). This

suggests that "it is crucial that state and local governments be provided

the opportunity to participate in decisions regarding Landsat policy,

technological capabilities and system characteristics" (C-26,39). As such,

"there is a need for some institutional mechanism designed to assure user

participation in systems planning and policy making" (C-26,25).

In relation to the systems characteristics, state and local

governments were particularly interested in a continuation of MSS data.

However, they also welcomed increased resolution imagery. If higher

resolution, satellites develop states would increase their overall use and

application of Landsat data (C-26,5-9). In general "many users favor

higher spatial resolution ... however as spatial resolution increases,

military security issues become obvious (C-24,17). While the U.S. expects

most countries to react favorably (UN 15) "it is likely that countries

already pressing for urgent development of a restrictive regime will argue

more strongly" (C-17,136). A further trouble with higher resolution is that

it "will result in a much greater volume of data for a given area." There

was concern "that this increased volume of data will exceed state and local

data handling and financial capacities" (C-26,28-29).

Finally in regards to private sector involvement, where the interests

of state and local governments collide head on with the private sector, "it

should be emphasized that the vast majority of states are planning to

develop their own internal Landsat data analysis capabilities and will not

rely heavily on the private sector for these services" (C-26,53). As such,

and "due to the public service nature of" Landsat, it "should be federally owned and operated, for at least the near term" (C-26,52). According to public sector interests, the private sector ought to provide specialized software and equipment; provide specialized or unique products and services; provide analysis service to local governments; and provide consultation on systems design and development (C-26,54).

Early in 1979, two more bills were submitted to Congress--S.875, the "Earth Resources Information Corporation Act" to set up a commercial earth resources information service, and S.633, the "Earth Data and Information Service Act" to set up an earth data and information service in NASA. The push for private sector involvement is fully evident in both these bills. S.875 would set up, within two years, a quasi-government, public organization along the lines of Comsat, while the other establishes an operational system within NASA, ncluding a seven year interim period (between inception and actual operational status. In this second bill, however, the established service would determine, after the interim period, what type of operational organization should run, the earth resources satellite system. In response, for the first time, the Prsident committed his administration to an operational system ... although it was left completely undefined (C-29,49). While this ended one debate--whether or not to move from an experimental to an operational system--it opened a whole range of new issues, controversy and debate continues.

The Department of State, mirroring international considerations changed its position, stating that an "operational system would improve the context for negotiation of international agreements on remote sensing" (C-29,163).

However, despite a seeming commitment to an operational system, continuity

of data remained a major consideration. "An underlying concern on the part

of those cooperating with us now ... is the lack of formal assurance that

the U.S. will provide ..." data continuity (C-29,162). And as the

administration moves to an operational system it must still recognize "...

the question of sovereignty over information pertaining to natural resources

... many developing countries are considerably concerned that advanced

countries and companies within advanced countries, might be able to exploit

them" (C-29,172). While the U.S. has never subscribed to this view it must

keep in mind that from a foreign affairs perspective, the major issue is not

whether the system is publicly or privately owned, but whether or not the

U.S. operates it in accordance with some agreed upon set of international

principles (C-29,174). And these principles are still (as will be discussed

later) in a state of flux.

While state and local governments continued to insist that the most

important issues are over a firm commitment and data predictbility, they

suggest that "the costs of a pay as you go system would effectively

discourage use at a time when the user base needs to be expanded so that it

can become self-supporting" C-29,107) and that a ban on data reproduction

would undermine the cost effectiveness of state use of Landsat data

(C-29,108). They therefore felt that the "service's charter should reflect

a public service concept and that Landsat type data should be considered in

the same context as census mapping and weather data ..." (C-29,107).

The private sector, on the other hand, suggested that a private system

operator would have to be able to retain appropriate data proprietary rights

and increase the price of data products in order to make the system

commercially usable (C-27,18). From one user's perspective, the government should commit to timely and continuous data; agree to purchase its own data; coordinate an international interface and it should establish international copyright laws (C-27,77). These are seen as essential for encouraging private sector interest and increasing the private sector market.

For the private sector, the major international issue remained "the extent to which the consent of a country should be required prior to dissemination of remotely sensed data or information on that ccuntry ... this will largely determine the extent of the utility of remote sensing satellite technology and the market for remote sensing satellite data" (C-27,30). Hence, because restrictions on data dissemination will dampen the potential market for private sector involvement and "any effectively preclude private sector undertakings in this area" (C-27,31), the private sector prefers an open dissemination system; but they also insist on copyright or proprietary data restrictions in order to protect the commercial viability of the system.

The development of competition from foreign countries became a further consideration. The European Space Agency (ESA) and France in particular are planning satellites. The ESA is planning a Land Applications Remote Sensing Satellite (LASS) and a Coastal Ocean Monitoring Stellite System (COMSS). These systems would be tailored to meet the needs of Europe and the Developing Countries" (C-27,18). Further, the ESA is setting up Earthnet "for the reception, distribution, analysis and sale of remote sensing data obtained from United States remote sensing satellite systems" (C-29,182). This would be in direct competition with the U.S. value-added service sector.

Further, the French are planning to launch SPOT.[6] They are already

selling Landsat compatible ground stations in competition with United States

companies. They have sold one to Brazil and are undertaking to provide one

to Bangladesh--a country where the U.S. is very much involved in remote

sensing.

Finally. the French have "made a proposal to the GEOSAT committee,

whose members are mostly U.S. corporations interested in natural resource

exploration, to modify the SPOT satellite to meet the needs of the GEOSAT

users. "The net effect of these initiatives could be a reduction of U.S.

technological ledership in space and the U.S. commercial position in the

provision of space services" (C-29,132). All of these things push the U.S.

government to move to an operational system, and to aid the private sector

in competing effectively with other countries in the international market.

Government Studies

As the positions of the various actors took shape, the government

studied the question. In a large study entitled the "Private Sector

Involvement Study," the government undertook to determine the feasability of

private sector ownership and operation of the system. This included the

means of subsidizing private sector involvement and how much that subsidy

would have to be. Generally private sector and public sector views clashed,

as described above. However a few new insights into private sector concerns

emerged.

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[6] Satellite Probatoire d'Observation de la Terre. This satellite will
contain two pointable multi-linear array sensors capable of operating in
both multi-spectral and panchromatic modes. Data will be 20 m and 10 m
resolution with possible steroscopic coverage.

On the emerging issue of foreign competition, the private sector suggested that an operational system was needed immediately. They expressed concern "that future foreign systems, especially if subsidized by their governments, may divide and undercut the market" (C-23, Appendix 5). They also felt that the U.S. should rethink its data flow policies. In light of potential competition from foreign companies wh will be using U.S. data, it may be necessary for the U.S. government and U.S. companies to cooperate vis-a-vis foreign companies who have the suport of their own governments (C-23,Appendix 5).

In conclusion, the private sector was not seen as ready to own and operate a remote sensing satellite system. They wanted the door left open to private sector involvement until the market is well understood (C-23, 7 and Appendix 5). While they felt that a mix of public and economic potential exists to keep the system flying they are concerned about limits on the data needs of some potentially large users. "Most firms cannot now assess the relative needs for repetitive as against non-repetitive use of Landsat data." They are concerned that some users will satisfy their long term data needs fairly quickly. In any case, private sector interests believed that without enhanced system capability, the market will drop off in the next few years (C-23, Appendix 5). Due to the uncertainty of the market, "the private sector considers that government subsidy and/or strong market support to private operations ... will be necessary in view of the markets current size and the public interest value of the system" (C-23,8). Interestingly enough, the private sector is able to use the public service argument to justify a government subsidy which would limit the risk of such an entrprise to private sector operators.

Finally, on the various options for private sector involvement, including a public sector corporation along the lines of COMSAT, a specialized market satellite targeted for a particular user, a leased services satellite, etc. most private sector users felt that a "pre-emptive designation of a national remote sensing entity, similar to Comsat ... would not be in the country's best interest at this time." However, they also agreed that whomever becomes the system operator will have to be assured of ownership and operation for a long period of time (C-23, Appendix 5). The private sector is not adverse to assuming the responsibility for the system if the government provided market support to make the risk acceptable.

The outcome of the study, was that the government would now assume that it was in the "national interest" to have a private sector owner and operator because the private sector would perform more efficiently and economically than the government, would more aggressively market the data and would stimulate technological development and transfer and would become more responsive to both public and private sector users (C-23,3).

The International Debate Drags On--1977-1979

During the 1977 meeting of the U.N. working group on remote sensing the members finally described in an orderly manner the system elements and data flow involved in remote sensing from satellite. These included

1. Data acquisition (satellites and command stations)

2. Data reception (antennae and receivers)

3. Data pre-processing (formatting and recording)

4. Data storage and dissemination (archiving and reproduction)

5. Data analysis (interpretation or user processing)

6.   Information utilization (practical application by users)

     (UN 15, pp. 8-9; C-42, 110)

Also in 1977 the Soviet Union had submitted a working paper which introduced

the concept of classifying data on the basis of spatial resolution.   It

broke the data down into three categories--local, which ranged from several

metres to 30-50 metres; regional which ranged from 50-100 to 300-500 metres

and global information which ranges from 500 metres to several kilometres

(C-42, p. 111).   This paper touched off a debate in the 1978 working session

of the working group which brought into "sharp focus the different views on

the significance" of the matter of spatial resolution.

The Soviets reiterated their position fully at the 1978 meetings.   They

suggested that the subcommittee should "take action to develop promptly

international legal rules governing the dissemination of data and

information derived from remote sensing of the earth, because what was at

stake was not only the economic sovereignty of states but also their

territorial sovereignty ... dissemination of primary data over 50 m spatial

resolution is allowable but any better data or any analyzed data ought not

to be disseminated to a third party without the consent of the country

involved" (UN 4, SR 195, 1978, p. 7).

This proposal met with approval only from countries closely allied with

the Soviets--those Eastern bloc countries including Hungary, Poland, E.

Germany, Czechoslovakia--and to some extent India.   It also drew strong

attacks on two grounds.   First, there were those who felt that there was no

scientific and technical justification for a spatial cutoff point.   (Canada,

Japan, Romania, etc., UN 4, SR. 194, 1978, p. 4-8).   Second, there were

those who felt that such a proposal did not go far enough in protecting the
sovereignty and rights of the sensed state. The delegte of Chile expressed
this concern, suggesting that global, regional and local classification for
dissemination of information was not a suitable base for the limitation of
remote sensing data dissemination (UN 4, SR.195, 1978, p.3).

At the same time international principles reaffirming national
sovereignty and the right of states to participate in remote sensing
activities and obtain technical assistance ballooned the number of working
principles from the five that the committee had in 1975 to 17 in 1978. Some
of these went back to the old arguments--including a principle on "full and
permanent sovereignty of all state and peoples over their wealth and natural
resources" "on advanced notification to a State whose territory will be
sensed" on "consultations between the sensing and the sensed states;" and on
dissemination of remote sensing dta or information" (C. 42, 114). Perhaps
most importantly,

on May 19, 1978, with Moscow, a convention was signed on the transfer
and use of data received through the remote sensing of the earth from
space. The signatures on that cvonvention were the representatives of
Bulgaria, Hungary, East Germany, Cuba, Mongolia, Poland, Rumania, the
Soviet Union and Czechoslavakia.

The basis of the convention is the principle of respect for the
sovereign rights of states over their natural reources. There is no
question that this also refers to information about the natural wealth
of sovereign countries (UN 3, pv. 183, 6/30/78, 41).

This convention endorses 50 m resolution and analyzed information restrictions, and a prior consent regime. It reaffirms the Soviet belief in the restricted dissemination of data which touches upon the defense and other sovereign rights of states." (UN 3, pv.183,6/30/78,pp. 41,51)

This seemed to signal the withdrawal of serious Soviet participatin in the development of a global remote sensing regime. This convention and several other proposals were carried into the 19th working session of the UNCOPUOUS. These other proposals included a U.S. working paper which would ensure that all countries undertaking a remote sensing program would report to the secretary general, to the fullest extent possible the nature and range of its program (C-42, 115). A Romanian proposal reasserted "full respect for the principle of permanent sovereignty ... including the right to access to information relating to: their natural resources (C-42, 115, UN 17). And a second USSR proposal which would require "a sensing state to inform a sensed state of the data acquired, and to transfer such data or information to the sensed state by mutual agreement" (C-42, 115, UN 18).

The issues of sovereignty and rights to information and the debate over the importance of classifying data by spatial resolution and then imposing a prior consent regime have led to a stalemate in the U.N. debate. While some progress has been made in developing principles, these key issues have not been resolved.

The French delegate summed the stalemate up soberly.

Can we at this session entertain any great hope of success with regard to remote sensing of the earth by satellite? ... the sensitivity of the question, the rapidity of technical progress and its complexity lead me to doubt that we can.   (UN 3, pv.193, 6/20/79)

In fact, any acceptance by the U.S. of principles limiting the dissemination of data by spatial resolution, or which ensure the transfer of data to a sensed country would run directly counter to U.S. policy to establish a commercial venture. The international debate and the goals of the government program to commercialize the system conflict with each other. This conflict was made clear in early 1980 when the executive branch reported its program. Although not a complete plan, as it left open the options to be pursued, it should serve as the focus of policy in the 1980's. In it, the following international policy objectives were listed:

-- "fostering international receptivity to and acceptance of U.S. remote sensing activities."

-- "developing a worldwide market for U.S. commercial data products and associated hardware and services."

-- "enhancing the technical quality and scope and reducing the cost of the U.S. land remote sensing satellite program."

-- "encouraging the utilization of land remote sensing satellite data and techniques in the national and regional development programs of developing nations."

-- and "maintaining U.S. commercial and technological leadership in the field of space remote sensing" (C-10,107).

It is clear from these policy objectives that U.S. confidence in any U.N. effort to develop an internationally agreed upon set of principles toward the formation of an international regime which was in the interests of the U.S. had diminished. Hence, the failure of regime formation activities led the U.S. to pursue remote sensing activities from a

domestic base and through direct agreements with those countries

participating in its program. Efforts at coordination are constrained by

U.S. private sector interest and the prospects of foreign competition from

the Soviets, the French, the Japanese and the European Sdpace Agency. It is

these international considerations, as well as to the debate over access and

dissemination of information which now impact U.S. policy.

The Government Reports

In defining the key issues is developing an operational system the

Executive Branch asked the following questions: First, what changes in

Landsat should be made in developing an interim operational system? Second,

what performance capbility should be developed for the next generaticn fully

operational satellite system; third, what policies should be adopted to

provide financing; fourth, how can eventual private sector ownership and

operation be achieved and fifth, how should U.S. plans for an operational

system be interrelated with the operational system plans of other

countries? (C-31,5)

In undertaking to answer these questions, the executive branch report

began with the following assumptions: The government will ensure the

continuity of data; an operational system will ensure appropriate

reliability and timeliness of standrd data products; users requirements, and

projected demand and cost will determine system design characteristics;

private sector involvement is a goal; prices should be set to ensure maximum

recovery of system costs consistent with the public good; a policy of open

dissemination will continue, including public non-discriminatory access to

the data; private sector ownership and operation of the system will be

conducted under government regulation, consistent with U.S. domestic and

foreign policies; the system will respond to U.S. federal interests and user

requirements with "due regard" for foreign interests; NOAA is to be the lead

agency for Land Remote Sensing Satellite Activities; (C-10,3) and "... a

fully operational satellite and ground system responsive to user

requirements could not become operational until 1989 at .he earliest"

(C-10,23).

These assumptions leave a large number of questions in the open. For

instance, what does "consistent with the public good" mean when discussing

price increases? What does "due regard for foreign interests" mean? How

are "projected demand and costs" going to be determined? And while the

government will ensure data continuity it is unclear whether they will

actually be able to achieve this unless the current satellites stay

operational past the launch of Landsat D, which has been delayed by

difficulties with the thematic mapper. It is these questions which the

report addressed, in part. The results of the study did not make any bold

new assertions, but outlined various options which could be pursued.

On the issue of government competition, the report suggested that the

impact of government technique and development training programs denied the

private sector access to some markets. Federal programs clearly compete

with private sector companies (C-10,91). Federal competition in services

includes inhouse preparation of information products which could hamper

technology transfer and the value-added services industry, and the

distribution of information by the government to non-federal users severely

limits the size of the potential market (C-10,90).

On pricing, the report suggests that while a premium price for privileged access to Landsat data would increase the system's payback, non-discriminatory availability increases the number of potential users and is consistent with a carefully considered U.S. policy (C-10,88). However, on data ownership, control over data and standardized products seems essential to private sector ownership. Copyright laws limiting resale and reproduction must become effective, dissemination of the data and products must take place only with appropriate fees being charged (C-10,87). While acknowledging the above considerations the government study concluded that market expansion is critical to private sector involvement. Such expansion required data continuity so that users could safely make investments in training and processing equipment (C-10,99). To encourage market expansion the government intends to tailor the system to user needs and to develop user benefits, this include training, applications development and applications demonstrations.

There is one difficulty, however, in tailoring the system--because the needs of the various users do not completely overlap (C-10,39-53). Further, helping develop users' benefits will force government programs to continue their role in technology transfer and the dissemination of data. This conflicts with the goal of private sector involvement. A Catch-22 pops up again in that the private sector will not take the risk until the government fully develops a user market which minimizes that risk and the government cannot do this without some user-oriented programs. This in turn is criticized as competition with the private sector and the private sector wants such competition stopped.

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The private sector is also wary of cooperation with foreign satellite operators. While coordination and complimentarity are fine there is a concern that this "may preclude the development of U.S. satellite system which could provide high market value and standardized data products ..." (C-10,92). This will also lead to a situation where U.S. industry will be competing with foreign companies who are assisted by their governments. Hence, some form of industry-government cooperation may be necessary. It may take the form of a subsidy or market guarantee. And it must be a long term commitment because the private sector doesn't want to get a government subsidy or guarantee only to have it suddenly disappear (C-10,92).

The pressures from the private sector are balanced by the caution of the state department. On prices, "it is essential that price increases be phased in gradually over time so that foreign ground station operators and other foreign users can accommodate the price increases into their planning and budgetary cycles" (C-16,64). One spokesman added that "to avoid international suspicion we need to provide direct readout, phase in price increases and have non-discriminatory access to data ... If we change these policies, which I think is essential in the course of turning the system over to a private operator, then I think the concerns that would be associated with private sector ownership would be very considerable indeed" (C-16,70). Essentially, from a foreign affairs perspective, the system can only be owned by a private sector operator with a great deal of regulation (C-16,71).

Needless to say the state and local governments were not pleased with the emphasis on private sector involvement, however, they suggested that they could accept a private sector owner if there is federal technology

transfer program, if there is state and local representation in system management and design and if prices are not increased too rapidly (C-16,87). In fact, they suggest that the price of data "should be limited to the cost of reproduction and handling and distribution." "Otherwise, some state and local government entities may be completely priced out of the market. A corrolary to this recommendation is the need for states to be able to reproduce land remote sensing data for their internal use" (C-16,83).

It becomes clear then that the thrust for private sector involvement is blunted by at least three things. First international concern over a private sector owner, state and local government objections to measures needed to bring about that ownership and the private sectors reluctance to take the risk of an operational system without an almost full government guarantee.

During the 1980 session of the U.N. Working group on remote sensing no progress was made toward resolving the critical issues on data dissemination.. And some delegations expressed concern over this lack of progress (OS961,p.8 (1980)).

In fact, to this date little progress has been made in reaching some form of agreement on the most basic questions regarding sovereignty over information and the type of dissemination regime to be implemented. In large part, those now pursuing the use of remote sensing data are likely to work things out in a local or regional context, as opposed to any global regime.

However, the working group was encourged by the full committee to keep
working toward the resolution of the policy conflicts (C-42, p.117).

More importantly for the U.S., "the challenge posed by foreign
initiatives in the remote sensing arena" was becoming "commercial as well as
technological" (C-27,19). In sensor technology, the French will be flying a
multi-linear array in 1984, the Japanese in 1984, and the U.S. not until
1989. There is also a good deal of foreign competition in ground station
technology (C-10,113). The French will launch SPOT in 1984. It will
include a 10 meter resolution pointable imager. And it will include a
capability for limited stereo data collection. They are working in
conjunction with Sweden and Belgium who will provide an onboard computer and
ground receiving equipment, respectively (C-8a,21). Further there has been
a "cordial" exchange of letters between GEOSAT and the French regarding the
SPOT system. The tone is "cordial" but it appears that in addition to
trying to meet the needs of the developing world, they will also try to
tailor the system to the needs of the GEOSAT users (C-27,139-140).

The Japanese are planning an initial launch of their Marine Observation
Satellite (MOS-1) in 1985, to be followed by five further satellite missions
in the yars 1985-1993. These will be for ocean and land observations
(C-8a,27).

Brazil and the Netherlands are beginning discussions regarding the
launch of their own national remote sensing satellites (C-8a,28). India
developed "Bhaskara," a rudimentary remote sensing satellite which failed
shortly after launch. Another is planned for launch in 1981. Also they
have plans for an Indian remote sensing satellite to be launched in the 1985
timeframe (C-81,25).

The European Space Agency has plans to launch two satellites, one an ocean monitoring satellite and one a land monitoring satellite. They are looking for compatibility of nationally owned systems, and they have tentative plans for Canadian cooperation--an exchange of ground processing hrdware for direct readout of data from the two satellites (C-8a,23,24).

And finally, the Soviet Union, although they have not started a "civil" program they have done some testing of coarse spatial resolution multispectral scanners on board their "Meteor" serites of meteorological satellites. And they have made data available through bi-lateral agreements (C-8a,27).

One Department of State spokesperson suggested that in looking to the future, "countries might be less satisfied with access to U.S. data than they might be with a system over which they have some measure of influence" (C-17,132). In line with this it is thought that charging a high price for Landsat data might allow foreign competition to undercut the U.S. "market" (C-10,112). Another spokesman cautioned that in the midst of growing competition in remote sensing it is well to recall that "a positive international climate will be invaluable as the U.S. pursues continued development and application of this important technology" (C-8f,7). In establishing an aura of cooperation through discussions on complementary systems, the U.S wishes to maximize potential usefulness of remote sensing data and to minimize duplication of effort. While limiting U.S. costs, the U.S. wants to limit possible dependence on other countries (C-10,116). This desire to establish complementary systems will constrain the scope of an operational system. This introduces "major uncertainties" in the evolution of a market which might eventually be self sustaining (C-12,9).

The Present

Following this report, and Congressional Hearings on the Executive Branch's plan, the Congress (Senate Democrats) submitted a bill to put most aspects of the plan into law. It was not passed. Meanwhile, the Executive Branch began moving system responsibility from NASA to NOAA. And the budget fight over Landsat funding continues. Not surprisingly, President Reagan and the Republican Senate are particularly interested in private sector initiatives in this area. Comsat again (it did so in 1979, 1980), has submitted a proposal for its taking over all civilian operational remote sensing satellite systems. It is apparently being considered, although other satellite manufacturers are not said to be happy with this.

Landsat D is slated for launch in late 1982 and observers can only speculate on the chances that Landsats II and III will provide data continuity. NOAA's present plan for the near term (the 1980's) calls for one operating satellite with one ground based backup to be used in case of satellite failure. Most observers feel that a one satellite system--with 18-day overflight intervals--will limit many application areas. The evolution of a civilian remote sensing satellite system is still largely in flux.

Part III.   EVALUATION AND ANALYSIS

This section of the paper will take the discussion developed in Part II and attempt to point out the policy tradeoffs which have come to the fore in the on-going debate.   In addition I will try to suggest the policy dynamics which underly the development of these tradeoffs.   In other words, I think that the policy dilemmas now facing the U.S. are a function of its own policies and the nature of the technology.   It is these things which I hope to illustrate in what follows.

In order to accomplish this task I have used a set of policy oriented questions developed at the Yale law school.   These questions should paint a complete picture of any policy situation and allow one to isolate not only the relevant actors and their positions, but also the dynamics of the situation, in overview form, these questions are as follows:

1.   Who participates?

2.   With what perspectives/demands?

3.   In what situations?

4.   With what capabilities?

5.   Using what strategies?

6.   With what short term outcomes?

7.   And longer term effects.

As these questions are answered in the following analysis, I believe that their utility for isolating important tradeoffs and policy dynamics will become apparent.

1.   Who are the participants/actors?

For the sake of simplicity and clarity we can break down the
participants in Landsat into two types--domestic and international. On the
domestic side the actors include state and local governments, the private
sector (including the satellite manufacturers, the value-added services
industry and the private sector buyer), the federal government includes the
Departments of Agriculture, Interior, State, Defense, Commerce and the
National Aeronautics and Space Administration, and the Congress.
Internationally, countries can be divided into a set of categories,
including Western developed countries, the Soviet bloc, and the developing
countries. Generally there are countries which have the technology and
support the "free flow" of information; there are countries with the
technology who support absolute sovereignty over resources and information
over those resources and there are countries who don't have the technology
but are desirous of using it (C-23).

One of the primary differences between the creation of Intelsat and the
potential for an international Landsat organization similar to Intelsat can
be found here--the actors involved. Intelsat was created by the U.S. and
other western countries. With Landsat, the entire community of nations is
represented.

2.   What are the perspectives (demands and expectations) of the actors
      involved?

Here I will outline the perspectives of the various domestic actors
involved in the policy process and then discuss the 'policy stance' that the
U.S. as a whole presents to the international arena. There are a set of

issues which can be touched upon, including the following (most of which are
tied up in the question of private sector involvement and the
commercialization of the system):

-- pricing

-- technology tansfer and technical assistance

-- data copyright and reproduction laws, including proprietary data

-- open dissemination of data, equal access to data products

-- system compatability

Pricing

Clearly, if the private sector is to take over management and ownership
of the Landsat system--if the system is to become commercially viable--then
prices must cover the costs of the commercial operation. This implies an
increase in the price of Landsat data and products compared to present
charges. The private sector, therefore, both the potential owners of the
system and the value-added services industry expect the price of raw data to
increase in the near future. However, they have generally agreed that a
phased increase is critical so as not to hinder market development
activities. Private sector buyers are not concerned, in general, about the
potential for an increase in the price of data, however, they would like to
see some form of data protection (proprietary data laws) in conjunction with
price increases.

State and local governments have been adamantly opposed to price
increases. However, they have become resigned over time to the likelihood
of phased price increases. They believe that remote sensing data ought to

be offered to users much like weather data--as a public service of the Federal government. While they have resigned themselves to the increase in prices they argue that private sector participation is not desirable. In general, they have adopted a strategy of trying to convince the Congress that their market will be largely taken care of with in-house capabilities.

The Federal government and its attendent agencies are in some disagreement over the issue of pricing. Generally, parts of NASA and NOAA agree with the OSTP and Congress that prices will have to increase. However they are less convinced that private sector participation in ownership of the system is inevitable. Only in NASA and in the Congress--along with the OMB, are people convinced that this is a commercially viable system and that it will indeed and should be transferred into the private sector. Many government officials (whom I have talked to) suggest that if Landsat is transferred into the private sector it will have to be heavily regulated. Particularly in the foreign affairs community there is less than overwhelming enthusiasm for private sector involvement.

In the international arena, the U.S. has presented a desire to move the system into the private sector with government supervision and responsibility. There have been complaints that this will reduce the potential for an international approch. However, from the discussion in Part II it should have been evident that with competing systems being developed and with the Soviets and the U.S. seemngly (at this time) deadlocked over a legal agreement in the U.N., the possibility of an international solution is improbable at best.

However, the issue of pricing is important from two other perspectives. First, in building a market for Landsat products the U.S. faces the same problem with the international users as they do with domestic users--an immediate, large increase in the price of data would dampen whatever market growth is taking place. Second, the French are likely to price their data products in a competitive fashion, and the Soviets may also offer terms favorable to foreign users. As such the U.S. may find itself in a bind. In trying to make the system commercially viable by increasing prices the U.S. may find themselves dampening the potential market for Landsat products. This is policy tradeoff number one: Increasing prices may increase the commercial viability of the system, but it may also allow foreign competition to undercut the U.S. share of the international and domestic market. A second important point is that raising the prices of the data and products may undermine the validity of U.S. international policies of open dissemination and equal access to the data in the system. If prices are increased to a commercially viable level, then the open dissemination and equal access system becomes an "equal access" for the rich, and not for the poor. This is policy tradeoff number two: Raising the prices of Landsat data in response to commercial pressures may contradict a carefully thought out U.S. foreign policy--and drive foreign users to other systems. In the following discussion, the interdependence of the various issues will become increasingly evident. Repetition may occur, however, think it is important to recognize the linkages amongst the various issues and the implications of various policy decisions on those issues.

Technology Transfer and Technical Assistance

As with the pricing issue, the private sector and the public sector in the U.S. are at odds over the issue of technology transfer. The private sector feels that this is an area in which the government competes needlessly with private sector firms. Generally, the private sector feels that it should be doing the technology transfer job--and that the government, particularly the EROS data center and NASA's technology transfer program ought to be cut back. At the same time, however, the private sector (those potential owners of the system) demands that the government "aggregate," or develop, the market and remove much of the risk of private sector ownership before the private sector will buy into the system. This forces the government to build the market without technology transfer and technical assistance. This is not likely to work. This is policy tradeoff number three: If the private sector wants the government to build the market then they will have to accept the government's role in technology tansfer and technical training and assistance, for the time being.

State and local governments are adamant on this issue. They suggest that the state and local market will only grow if there is a proper means of technology transfer from the government to them. They further argue that they must have help from the federal government as they cannot expect to make an investment to use the system without knowledge of whether or not the system is goiong to be worthwhile to them.

The Federal government runs several technology transfer and technical assistance programs both domestically and internationally, including those in NASA, AID and the Department of Interior. Beyond the bureaucratic

self-preservation motive, these programs were seen as essential to building
a political constituency for Landsat and are now seen as essential to the
market building process. In particular, technical assistance programs in
developing countries are an integral part of U.S. foreign policy regarding
Landsat. Since the opening of the international debate on remote sensing,
the U.S. has offered technical assistance and training to the developing
countries. This seems to have made the open dissemination policy more
palatable. If technical assistance was not available then the open
dissemination policy would only be open to the technically sophisticated
countries of the world. This is policy tradeoff number four: If the U.S.
stops its international technical assistance programs it is likely--in
international forums--to undermine the long standing U.S. position on open
dissemination and technical assistance. It also might drive foreign users
to another satellite system. In fact, as noted above, competition is
emerging. Clearly if these competitors offer to the developing world terms
more attractive than the U.S. can, they will undercut the U.S. share of the
international (and perhaps the U.S. domestic) market.

Data Copyright and Reprodution Laws

Another issue tied up with potential private sector involvement in the
ownership of the Landsat system is that of data copyright and reproduction
laws. The private sector, in order to maintain and develop the commercial
viability of the Landsat system requires that some form of data copyright
and reproduction laws be instituted. Further, they may require that Landsat
data, where possible, become proprietary. The mineral exploration community

has suggested that they would pay a great deal more for the data if it was proprietary.

While this may be an essential step in developing the commercial integrity of an operational/commercial Landsat system, other actors are against it. State and local governments are again adamant in opposition to such laws. They suggest that they need to be able to reproduce the data once they have it in order to make Landsat a cost-effective tool. If they are not allowed this type of in-house capability they are likely to return to more traditional methods of data collection. (This is unlikely in the opinion of this author.) In other words, any sort of proprietary data or copyright laws would discrourage state and local government use of Landsat data. In the international sphere this type of policy would run into similar problems with the foreign users--particularly those developing countries who are worried about the use of Landsat data by multinational corporations to exploit the resources of the developing countries. Also, forbidding data reproduction would make it harder for them to justify Landsat in that its cost-effectiveness would decrease.

The Federal government is split on this issue. Those agency's which are user agency's are more in favor of not having copyright laws while those that are pushing for commercialiation think that such a law is essential to the health of the enterprise. These are policy tradeoffs five and six: If the government institutes some form of copyright or proprietary data laws for Landsat then they are likely to dampen the potential mrket due to the decreasing cost-effectiveness of Landsat. However, the remaining market may be willing to pay more for data. And if the government institutes a

restrictive policy it will undermine the U.S. policy of "open dissemination" and equal access to the data internationally. (Here, open dissemination would mean that anybody could buy the data, on the condition that they are eligible under the copyright laws or that they somehow meet the proprietary law requirements. What is an open dissemination policy to the U.S. may not be an open dissemination policy to the rest of the developed world and particularly not to the developing world.)

Open Dissemination and Equal Access to the Data

Up until now the U.S. has presented a strict policy of open dissemination and equal access to Landsat data on a nondiscriminatory basis. This policy is fully supported by state and local governments and by most federal agencies, strongly by those who deal with foreign affairs. However, due to the push for commercialization, this position might have to change. As private sector actors have become increasingly involved, there have been suggestions to the effect that guaranteeing access to data may not be in the "national interest" at this time. At the same time restrictions on data reproduction and data dissemination due to copyright laws may be seen internationally as posing unfair restrictions on access to the data.

Foreign actors have a range of views on this point. First the Soviet bloc believes in a restricted dissemination regime--with an emphasis on prior consent--i.e., that data on one country would not be given or sold to a third country without the expressed consent of tht third country. At the same time, data on a country must be made available to that country from the sensing state. The developing countries are even more adamant in this

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stance, although their actions in signing "open dissemination" agreements

for their ground stations make their policy position a bit hollow. They

strongly believe that the data should be completely available to the country

sensed but that prior consent is needed to send the data to a third

country. The French, who started out adamant in their support of a "prior

consent" regime have now softened their position, although they still claim

to suport such a regime. This may have something to do, as does the Soviet

position, with trying to gain a share of the market for remote sensing data

by catering to the demands of the developing world. However, as the

realities of operating an operational system approach, they will--it is the

guess of this author--be forced to continue to soften their position on

restricted dissemination of data in the sense of a prior consent regime.

Here is the crux of the issue. The U.S. believes that an open dissemination

regime guarantees the widest possible potential market. However, they

believe that given that anybody can buy data about any other

country, there will have to be copyright and proprietary data laws to

protect the commercial integrity of the system. The developing countries

are in favor of a prior consent regime which would surely dampen the

international market. However, even those that have come around to support,

at least tacitly, an open dissemination policy would likely be put off by

such copyright laws. Hence, policy tradeoff number seven: If the U.S.

decides to go ahead with these laws there are likely to be repurcussions

amongst foreign users--particularly the developing countries who are likely

to see this as an unacceptable form of restricted dissemination. At the

same time, these laws which are instituted to enable a commercial system

might dampen the market for Landsat data as foreign users move to competitive systems whose technology and policies is tailored to their needs.

System Compatibility

As remote sensing systems move into an operational phase, the question of whether the various national systems will be complementary or competing has been raised. In general the users of the data, whether they be foreign or domestic, believe that system compatibility is extremely important. This would enable a user to use one set of equipment to take advantage of several sets of data. However, those putting the satellites up are a bit wary of developing completely compatible systems due to fears of over specialization and losing parts of the potential market. Private sector firms in this country are not likely to be in favor of system compatibility because it tacitly implies foreign input into their business decisions. No American or foreign firm is likely to support such a development. However, there is likely to be a push for those who are funding the system to develop compelementary systems in hopes of keeping the cost of the total operational system as low as possible. This leads to policy tradeoffs numbers eight and nine: If the government decides to develop complementary systems in order to please users and keep operational system costs down they are likely to discourage potential private sector investment. If they push for competing systems they may well find parts of the potential market pulled out from under them as well as finding technological leadership slipping away. This may leave U.S. industry in a disadvantaged position, in that most foreign

competitors will be working in conjunction with their governments, thereby putting U.S. companies in competition with foreign governments. This is not a place U.S. companies want to be.

In sum, on the theme of actors and their perspectives, state and local governments and foreign actors stack up as opposed to the private sector. This has put government agencies into a difficult position. Rather than trying to solve the particular policy issue confronting the government, I will complete this analysis with the hopes of uncovering the dynamics by which this sticky situation has come about.

3.   In What Situations do the Actors Participate?

There seems to be two situations or levels of activities which emerge. First, there is the everyday--what I will call short term--activity. A second level of activity--which I will call the long term or negotiating activity--is that activity which goes on in order to regulate the technology in the future. The reason for this distinction will become apparent shortly. In general, what an actor suggests they want, and what they are actually doing are not always one and the same thing. While this might strike one as being somewhat contradictory and irrational, in fact, it may well be a quite rational thing to do.

4.   With what Capabilities do the Actors come to Policy Process?

Here we will focus on the technological and market capabilities which each actor comes to the process with. While this leaves out the idea of "bargaining capability" I suggest that such a capability is much less knowable and hence more difficult to factor into any policy analysis.

In terms of technological capabilities we can distinguish at least three types. Those countries which have the cpability to launch and maintain an operational satellite system will be countries with "high" capability. Those countries who do not have that capability and do not wish to develop it, but have sufficient technological expertise to utilize the data from the technology will be said to have "medium" capability. Those with neither will be said to have "low" capability.

In terms of market capability we can classify actors by the size of their potential market. While this is quite a bit more elusive than technological capability it becomes an important factor in discussing the policy process--and who gets attention paid to their perspectives. Generally, state and local actors are seen as having a relatively small market potential, privte sector actors as having larger potential, the developing countries still larger and the federal government as having the greatest potential market. In terms of technological capabilities the U.S. (as an actor) is seen as having high capability, the Soviet Union and France as having high capability, developing countries as having from low to medium capability and other developed countries somewhere between medium and high capability. Internally to the U.S. state and local actors are moving from low to medium while the private sector actors range from high to medium depending on whether one is discussing the satellite manufacturers, value-added services industry or the buyers. It is important to note that this is where these countries and actors are now--this is not where they started. The process by which countries gain technological expertise and thereby change their level of capability is important for the policy implications of this analysis. That will come shortly.

5.   What Strategies do the Various Actors Use?

First, in the international sphere--because all actors operate on two
levels simultaneously we woud expect two sets of strategies.

In the internatinal negotiating arena there are three main strategies.
The first we will call legalistic. This is pushed by those who believe that
remote sensing data is a threat to national soveveignty and desire some form
of prior consent dissemination (and acquisition) regine. A second strategy
is the operational strategy. This strategy is pursued by those who have the
technology or have adequate access to it, are against a prior consent
regime, and want to develop the technology first and regulate secr᠎᠎᠎᠎   ᠎
third strategy is a middle strategy which suggests that there is ᠎᠎᠎᠎. a
fundamental contradiction between sovereignty and the free flow of
information and which tries to run a compromise course between those who
desire a prior consent regime (the legalizers) and those who desire an open
dissemination regime (the operationalizers). There is another type of
policy much akin to the operational strategy that of the organizational
strategy. This strategy suggests that the development of proper
organizational strcutures/institutions would define more clearly the type of
legal restraints needed.

Developing countries--those with low capabilities--have pursued a
policy in the international negotiations of regulation first. Believing in
the need for a prior consent regime they have pursued a "legalistic"
strategy. However, at the same time they have made an effort to improve
their technological capability. This has meant dealing, in large part, with

either the U.S. or the Soviet Union. In gaining technological expertise
they have had to give up some things--generally policy support. In short
term activities then they have tended to accept the policy of the country
from whom they received technical assistance, while at the same time
maintaining a position eemingly contradictory in the international
negotiations. This was justified, and has been up until now on the basis
that the systems were experimental and that what was being debated in the
international sphere was an operational system. I will return to the
importance of short-term activity taken in the context of an experimental
system in the next two sections.

The legalistic strategy is also being followed by the Soviet Bloc.
This is for two reasons. First they believe strongly in the absoluteness of
sovereignty over resources and information and the need for a prior consent
regime (this also has to do with their worries over possible military uses
of the satellite against them). Second, this is an effort to cater to the
needs and desires of the developing world. Whether it is seen as a
political struggle for world dominance or an economic struggle for markets,
the fact is that the U.S. and the Soviets compete for the "hearts and
minds," and pocketbooks of third world leaders. Hence, in the short term
they pursue the same strategy--that of building a political constituency
around their particular political preference. This includes the trading of
technical assistance and policy promises for policy support in the
international forum. Hence, while the developing nations are building their
capabilities and their market potential, the superpowers, as the other half
of that process, a e building what they hope will be an effective political
constituency.

In the longer term the U.S. and its western allies are pursuing an operational policy in response to their belief in the "free" flow of information and their opposition to a prior consent regime. However the Western allies are, at the same time, building up their own capabilities which may shift their position in the long term negotiating arena.

Finally, there are the French. They began with an ambition to break into the space power club and a belief in the strictist sense of sovereignty over resources and over information about those resources. Hence, they have pursued a legalistic approch in the international negotiations while developing on their own a capability for remote sensing. This is likely to thrust them into a new role--and we are likely to see their politics change in response to that new role.

In particular, as the French move into operational competition we would expect them to begin a political constituency building process--which in an operational system is the same as a market building effort. The U.S. at the same time, will also be looking to build a market as the system goes operational and we have already seen how this is made difficult by various competing actors. In fact, as I will try and point out in the next section, it was the political constituency building process which makes it now so difficult to change course and turn to a short term policy of market building and commercialization.

b.   What have been the Short-Term Outcomes of These Actions/Strategies?

The outcomes of these strategies has been a solidifying of the Soviet Bloc around a policy of prior consent and regulation of remote sensing satellite systems. For the U.S. and the developing world the outcome has

been a gradual shift away from the dogmatic positions which the developing
countries originally brought to the international negotiating process. As
the U.S. built its political constituency through the use of technical
assistance and international participation in the Landsat program
(particularly the spreading around the world of ground stations with written
agreements on cpen data dissemination) the vanguard of the developing
world--Argentina, Brazil and Mexico and Chile--backed off a bit on its push
for treaty provisions. While still maintaining their strong position on
abolsute sovereignty and prior consent, they have eased off on rhetoric and
the drive for a treaty. And the U.S. has gained wide acceptance of its
satellite system. At the same time the French have become a high capability
power in this area--with plans to launch a competitive system called SPOT.
This makes at least three nations with plans for remote sensing satellite in
the next few years, with the Germans, Japanese, Indians and the European
Space Agency not far behind. As such, in the short term, the capabilities
of the various international actors involved have changed radically, in part
due to the U.S. strategy of political constituency building and in part due
to an explicit desire to "compete." This includes the development of
competition in Europe via Earthnet, a ground station system which wil`
compete with U.S. ground stations, and ground station builders for the
international market.

In general as countries have moved ahead technologically via short term
policy decisions, they have maintained their position in the longer term
negotiations. What they have given up is the short term political support
of the U.S. system. With the advent of legitimate competitors, however,

this support does not bind the developing countries--who can simply move to another system unless the U.S. and the French (in particular) can come to some agreement on system sharing. As such, the U.S. has been through its policy of constituency building, successful in isolating the Soviet Bloc and forestalling the development of a prior consent regime and a legalistic approach. In fact, their operational approach has been dominant. However, the cost has been the creation in part, of competition and a set of "weaker" actors who are now in a stronger bargaining position due to their increased capabilities and the reality of competing systems. In particular, as the U.S. now tries to commercialize the system, they may find themselves running. into opposition from those very countries in which they created the future potential market during the political constituency building stge of their strategy.

In sum, the short-term outcome of the various strategies has been a redistribution of capabilities amongst the actors involved and the formation of "coalitions" of actors around the various viewpoints developed in the international arena. At the same time the technology has moved well along toward an operational phase.

7.   What are the Longer Term Effects of the Policy Process?

The longer term effects of the various policies pursued will become evident in future negotiations and short-term activities. They are impacted by the short-term outcomes summarized directly above. We can expect that those countries whose capabilities have changed will change their long term negotiating strategy. In particular we can expect that developing countries

will now push hard for system complementarity. At the same time, having failed in an initial legalistic thrust--moving into an operational period--I would expect the developing countries to develop regional programs and bi-lateral agreements for governing remote sensing activities.

I expect that the Soviet Union will continue on its present course--pushing for a modified prior consent regime with some sort of resolution cut-off point. As they develop an operational capability they may well set up an alternative system. They will change their strategy if they desire to capture more of the world market and as they respond to the demands of the developing world.

The U.S. will likely continue its push for an open dissemination system, hoping to maintain the potential for the largest possible international market. They are likely to be more favorable to system complementarity as the prospect of U.S. firms competing with foreign governments emerges. Generally, the negotiating process should stall until the time (if and) when the U.S. and the French agree that the system is not commercially viable. At that point interests may converge enough to enable the development of a successful international treaty or regime.

Domestically, however, there is no reason to think that the primary thrust to move the system into the private sector will change. Until, as noted directly above the private sector declares or the government realizes that the system is simply not commercially viable, the effort to make the system commercial will continue.

However, once again short-term strategies may outrun the long range negotiations and change the picture drasticlly. As the developing countries continue to develop their own capabilities and in an effort to play the

French, the U.S. and the Soviets off against one another to get the best

deal, they may well drive the governments of those countries to the

realization that the system is too political to be commercially viable. At

the same time the U.S. will be, and the French are likely to be, in the

midst of a market building strategy. However, at least in the U.S. this

strategy is being carried out for the time being in the government, in

NOAA. If the seven year interim period is seen through to its entirety the

difficulty of moving an entrenched bureaucratic program into the private

sector might be too much. As such, the possibility for a compromise and

international arrangement is likely. Again, it hangs on the commercial

potential of the system.

The ironic thing in all of this is that the U.S. may have

created--through its long delay in moving to an operational system and

through its political constituency building strategy--the very conditions

which will make it impossible to commercialize the system. These same

conditions making comercialization impossible will make the possibility of a

successful international negotiation more likely.

Summary

In sum, this section has been an effort to systematically outline the

policy issues facing Landsat policy makers at this point in time, with an

emphasis on the development of the policy context they find themselves in.

The primary lesson to be learned, I think, is an old one--we lie in the bed

that we have fashioned. The decisions we make today will create the

domestic and international environments in which we will have to work

tomorrow. In particular, policy makers ought to remember the following things:

1. Technology is nearly impossible to control--it will diffuse and competitors will develop. Technological monopolies will not last. This may in fact be part of a conscious policy to develop acceptance of the new technology by allowing technology transfer and international participation.

2. The process of political constituency building will speed the transfer of technology and the building of capabilities in other actors. This will change the shape of the "negotiating" table and will also make those actors important as part of the potential market for an operational and commercial system. With the development of competition, this will further strengthen their negotiating position.

3. The very policies that we adopt in order to gain support for an experimental system may stand in the way of policy choices for an operational system. In particular, the decision to push for an open dissemination/equal access data regime during the experimental period will make it very hard for the U.S. to now go back and reverse its policy in deference to private sector needs.

4. The process of building a political constituency for an experimental technology increases not only the capabilities of other actors but also their legitimate claims upon the 'system.' In fact, by building a political constituency, you also create that many more potentially legitimate competing claims on policy makers.

The moral of this paper can be summed up in three major points. First, technology doesn't stand still. As it moves from an experimental stage into operational use, the intrests and perspectives of the various actors chnge. Second, the interests and capabilities of the actors change through time in response to their own policy decisions and the efforts of the high capability powers to build political constituencies. Third, and most importantly, the policy decisions taken in early stages of technological development will shape the environment of the later stages. And in fact they will be hard to change. Unfortunately they may well be in opposition to the changed interests of the country which introduced the emergent technology in the first place.

As will be discussed in the conclusion to this paper, it is thought that undertaking the exercise gone through above at the outset of a policy process might help to form a policy with not only an eye to present circumstances but the likely emergence of changed capabilities and interests.

Conclusion

This paper has been an attempt to accomplish three things. First, it attempted to outline the development of policy regarding Landsat. This should be useful as an historical document in and of itself. Second, I attempted to show that one can systematically analyze the politics, and economics which are involved in making policy regarding emerging technologies. And, third, I used this systematic analysis to clarify the trade-offs which confront policy makers today.

In sum, the conclusion of this paper are simple enough. The decisions and policies which we pursue today constrain and limit our policy options tomorrow. We create our own political and economic environment and hence short-term policies should be calculated with that in mind. And I believe that certain patterns of technological development can be isolated which have general applicability. These include the maturation of the technology from experimental to operational status; the diffusion of technological capabilities regardless of protections against technology transfer and particularly if policies of political and/or market building are followed; and as the technology moves into an operati,nal phase, and as it difuses, the interests of the various actors involved--including the technological leader--will change. It will be useful to think of these things in the context of policy making regardng direct braodcasts satellites, the technology for exploiting the oceans, an oceans remote sensing satellite, future weather satellite systems, weather modification technology and the technology of transborder data flows--computer information networks.

Finally, in facing a complex and interdependent future it is hoped that a political systems study such as this one will enable more efficient and effective policy making by pointing out the inherent and inevitable trade-offs between the politics and economics of emerging global technologies.

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FINANCIAL ASSESSMENT OF THE SPACE OPERATIONS CENTER
AS A PRIVATE BUSINESS VENTURE

Michael Simon
January 1982

Abstract

The possibility of private financing and operation of the Space
Operations Center (SOC) is considered as an alternative to SOC development
by the government. A hypothetical revenue model for SOC services is
constructed and is compared with NASA estimates of SOC development and
operating costs. A present-value analysis based on a 1985-2000 investment
horizon shows a potential for substantial profit in a private SOC venture,
although the possibility of large losses is not discounted. Present-value
estimates range from $8.6 billion down to a low of minus $3.3 billion.

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I. INTRODUCTION

The idea of establishing a permanently-manned space station in Earth-orbit is not a new one. Scientific work on this subject dates back to the early 1900s, and studies have identified many possible design configurations for such a facility. The National Aeronautics and Space Administration (NASA) recently formed an office to study the multi-purpose Space Operations Center (SOC), which now appears to be a likely candidate for a manned U.S. space station.

Early studies of the economics of the SOC have raised an interesting question: could a facility such as the SOC be built and operated for profit by a private organization? Government and industry are likely to find this question increasingly relevant as man's role in space expands. As the commercialization of space communications is followed by the opening up of markets for space processing, space energy systems, and space habitation, the opportunities for profitable endeavors in space will multiply. A space operations base would play a pivotal role in this entire industrialization process, and private ownership of a space station would be consistent with American ideals and historical precedent. As this paper will point out, such an enterprise might also be financially attractive.

II. THE SOC MISSION MODEL

The major obstacles to the private financing of a SOC are similar to those for other proposed space projects: a large up-front investment, long lead-time, and high risk. Unlike programs such as the satellite power system, however, the SOC would provide a wide variety of basic services, most of which are essential for the realization of widely-accepted near-term space goals. The versatility of the SOC would guarantee an active market for SOC services, and would help to insure financial success in such operations.

By the early 1990s a SOC could be involved in dozens of independent space operations. These can be divided into three categories: basic operations, military operations, and specialized operations. Basic operations are those whose profitability are easiest to predict, and which would be most likely to provide economic stability during the critical early years of SOC operations. Basic operations consist of launch services (from low-Earth to geosynchronous orbit) for communications satellites, and space science services. Military operations are potentially as valuable as basic operations, but cannot be assessed without the involvement of high-level defense authorities. Military operations could include the launch,

storage, repair, and protection of military satellites, Earth and
space observations, and possibly even space construction.
Whether the military would be willing to have these services
provided by a private organization is questionable, but such
cooperation between the military and industry would not be
unprecedented. Finally, specialized SOC operations would offer
the potential for the long-term growth of SOC activities,
although the SOC could be involved in such functions by the early
1990s. Specialized operations include launch services for
non-communications payloads, satellite servicing, and, most
importantly, materials processing in space (MPS). MPS alone
could provide several billion dollars of SOC revenue annually by
the end of this century. Other specialized operations such as
space construction and the processing of non-terrestrial
materials are also compatible with, if not dependent upon a SOC,
but will not be considered in this financial assessment.

III. BASIC OPERATIONS

One of the major functions of a Space Operation Center would
be the delivery of communications satellites to geosynchronous
orbit. The SOC would be located in low Earth-orbit (LEO), within
range of the Space Shuttle. Communications satellites could be
launched from Earth via the Shuttle, and then transferred at the
SOC to reusable, chemical-propulsion orbital transfer vehicles
(OTVs). The OTVs would have a payload capacity of about 12,000
pounds, and could deliver as many as four satellites at a time to
geosynchronous orbit. It is likely that two OTVs could be
berthed at the SOC at all times.
The profitability of launching communications satellites via
the SOC would depend upon a number of factors. These include,
primarily, the demand for space communications and the cost of
operating the SOC OTVs. Since we have had considerable
experience with space communications and various types of launch
vehicles, it is not impossible to evaluate these conditions.
Demand for the launch of communications satellites is expected to
increase dramatically by the 1990s, with over 150 communications
satellites expected to be in orbit by the year 2000. Many of
these satellites will be very large in comparison with today's
communications satellites, and the SOC would be particularly
valuable for the launch of these large payloads. Table 1 shows
projections of the demand for launches of various sizes of
communications satellites over the next twenty years. To support
this level of traffic, approximately 100 OTV flights would be
required during the 1990s. (ref. 1).
The costs of utilizing SOC (or space-based) OTVs for delivery
of these satellites can be broken down into three components:
development costs, unit costs, and operating costs. Development
costs (DDT&E) for SOC launch services consist of the cost of
developing the OTV launch system, which can be estimated at about
$1 billion. The unit cost (cost per OTV) could range from $35
million to $110 million per vehicle. Operating costs include the

Table 1

Satellite Launch and Shuttle Flight Requirements
(Communications Satellites)

Year	Satellites in Orbit Size*				Satellites Launched Size*			Number of Shuttle Flights
	Total	A	B	C	A	B	C	
1982	33	23	14	1	8	4	1	5.00
83	47	28	18	1	10	7	0	6.00
84	57	32	22	3	9	8	2	8.25
85	66	37	25	4	11	7	1	7.25
86	75	40	29	6	10	9	3	10.00
87	85	44	32	9	11	8	5	11.75
88	92	47	35	10	11	9	3	10.25
89	101	50	38	13	11	9	5	12.25
1990	108	51	41	16	10	10	6	13.50
91	116	53	44	19	11	10	6	13.75
92	123	54	47	22	10	11	7	15.00
93	127	55	48	24	10	9	6	13.00
94	134	55	51	28	9	11	9	16.75
95	139	54	53	32	8	11	9	16.50
96	144	54	55	35	9	11	9	16.75
97	146	53	55	38	8	9	9	15.50
98	149	50	57	42	5	10	11	17.25
99	151	50	57	44	8	8	9	15.00
2000	153	48	58	47	6	9	11	17.00
2001	156	48	58	50	8	8	11	17.00
2002	158	47	58	53	7	8	12	17.75
Total					190	186	135	275.50
Average Per Year					9.05	8.86	6.43	13.12

*A = Delta equivalent, B = Atlas Centaur equivalent, C = IUS equivalent

From: "Forecast of Space Shuttle Requirements for Launch of Commercial Communications Satellites," Future Systems Inc.. Sept. 6, 1977.

cost of periodically refurbishing the OTVs (estimated at $20 million to $50 million every ten flights, plus $60 million for transportation of the OTV to Earth and back to the SOC each time), the cost of delivering communications payloads to the SOC via the Shuttle ($12 million per OTV flight), and, most importantly, the cost of delivering fuel for the OTVs to the SOC (about $42 million per OTV mission). These costs are summarized in Table 2; the high cost estimates have been used for conservatism. The total cost per OTV flight, including amortization of development costs, is slightly over $81 million. (ref. 2).

The best way to estimate the profitability of SOC communications launch services is to compare the cost of utilizing the space-based OTVs with other possible launch methods. The cost "savings," or the difference between the cost of using the SOC OTVs and of the other launch vehicles, represents an upper bound on the profitability of the SOC launch system. The SOC OTVs could be compared with today's expendable launch vehicles (Delta, Titan, etc.), but since the expendables are almost certain to be obsolete by the 1990s, this would not be a valid comparison. One exception might be Europe's Ariane expendable launch vehicle, which is expected to provide NASA's Space Transportation System with stiff competition for launch services for certain types of payloads. When relable data about the costs and capabilities of Ariane's future syatems (Ariane II, III, and IV) become available, it could influence the results of this assessment.

Another possibility is to compare SOC OTV costs with the expected costs of the Shuttle upper-stage boosters, the SSUS-D, SSUS-A, and IUS. The upper-stage costs are shown in Table 3. When compared with the SSUS and IUS, the space-based OTV shows a dramatic cost advantage, with average annual savings of over $500 million during the 1990s. Figure 1 shows OTV savings as a function of the demand for the launch of communications satellites. Even if demand varies from current projections, the space-based OTV is likely to have a significant cost advantage over the Shuttle upper-stages.

However, the Shuttle upper-stages may also be obsolete by the 1990s, even though they have never been used to date. If the upper-stages were the only alternative to the SOC OTVs, a company operating a SOC could conceivably earn annual profits of close to a half a billion dollars on communications satellite launch services. It is not difficult, however, to envision other launch systems capable of competing with the SOC OTVs. The closest competitor appears to be a single-stage Earth-based OTV, which would be launched directly from the Space Shuttle and which would resemble the proposed Shuttle-Centaur launch system. It too would be likely to have tremendous cost advantages over the Shuttle upper-stages, as illustrated in Table 4. (Table 4 also includes data on a 2-stage Earth-based OTV system which would not depend upon the Space Shuttle. This system is not competitive with the other options.)

Given optimistic cost-estimates for the single-stage Earth-based system (a worst-case condition for the SOC, again a

TABLE 2

COSTS OF ALTERNATIVES TO SHUTTLE UPPER STAGES

(100 MISSIONS)

SPACE (SOC)-BASED OTV

DDT&E	$1000 M
UNIT COST (6)	660 M
REFURBISHMENTS	450 M
	$2110 M

/100 $21.1 M/FLT.

FUEL COST (PER FLT.)
42,000 LB @ $1000/LB
=$42.0 M/FLT.

OTV TRANSPORTATION
(TO SOC FOR REFURBS)
=$6.0 M/FLT.

COST OF PAYLOAD TO SOC
(VIA SHUTTLE)
=$12 M/FLT.

$81.1 M/FLT.

EARTH-BASED OTV (2-STAGE)

DDT&E		$1000 M
UNIT COST		
Lower Stage (6)	660 M	
Upper Stage (100)	3000 M	
REFURBISHMENTS (9)	450 M	
		$5110 M

/100 $51.1 M/FLT.

PAYLOAD & FUEL COST
2 SHUTTLE LAUNCHES
$120 M/FLT.

$171.1 M/FLT.

EARTH-BASED OTV (1-STAGE)

DDT&E	$1000 M
UNIT COST (100)	2000 M
	$3000 M

/100 $30.0 M/FLT.

PAYLOAD & FUEL COST
1 SHUTTLE LAUNCH $60.0 M/FLT.

$90 M/FLT.

Reference: Johnson Space Center (NASA) SOC Program Office; in-house estimates

TABLE 3

COSTS OF SHUTTLE UPPER-STAGES

		Payload Dependent Charges

TRANSPORTATION (STS) COSTS

SSUS-D
Length: 7.75 ft.   Load factor: 7.75/60 = .13
Weight: 6,528 lb.   ": 6528/65,000 = .10 - Charge factor = .13/.75=.173; Charge=$9.4M+1.2M=$10.6M

SSUS-A
Length: 7.5 ft.   Load factor: 7.5/60 = .125
Weight: 12,600 lb.   ": 12,600/65,000=.194- Charge factor= .194/.75=.258; Charge=$14M+3.9M = $17.9M

IUS
Length: 16.8 ft.   Load factor: 16.8/60 = .28
Weight: 41,500 lb.   ": 41,500/65,000=.638- Charge factor= .638/.75=.851; Charge=$46.3M+10M=$56.3M

UPPER-STAGE UNIT COSTS

SSUS-D - $6.6M
SSUS-A - 8.8M
IUS   - 40.0M

UPPER-STAGE TOTAL COSTS

SSUS-D - $10.6M + 6.6M = $17.2M
SSUS-A - $17.9M + 40.0M = $26.7M
IUS   - $56.3M + 40.0M = $96.3M

Figure 1

EFFECT OF DEMAND FOR STS UPPER-STAGE FLIGHTS ON OTV ANNUAL SAVINGS

(S.O.C.—Based OTVs)

Projected upper-stage flight
requirements for launch of GEO
communications satellites
(average annual, 1990–2000;
SEE Table 6)

IUS

SSUS-A

SSUS-D

Number of upper-stage equivalent payloads

Annual
Savings
(Millions
1981 $)

467.9

-26.4

TABLE +
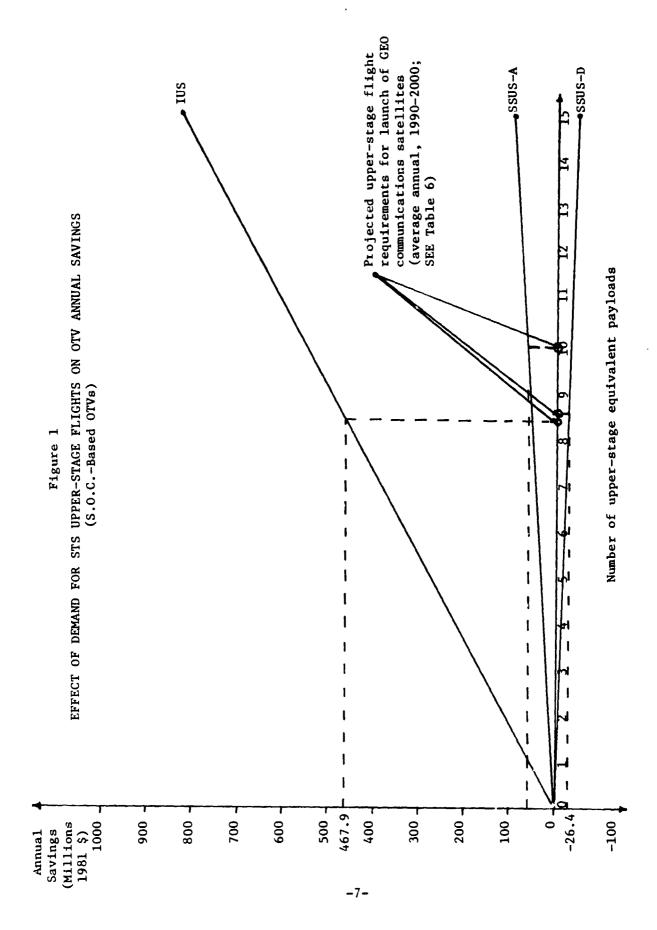
SHUTTLE UPPER-STAGE/OTV COST COMPARISON

SINGLE PAYLOAD COST TO G.E.O
(MILLIONS 1981 DOLLARS)

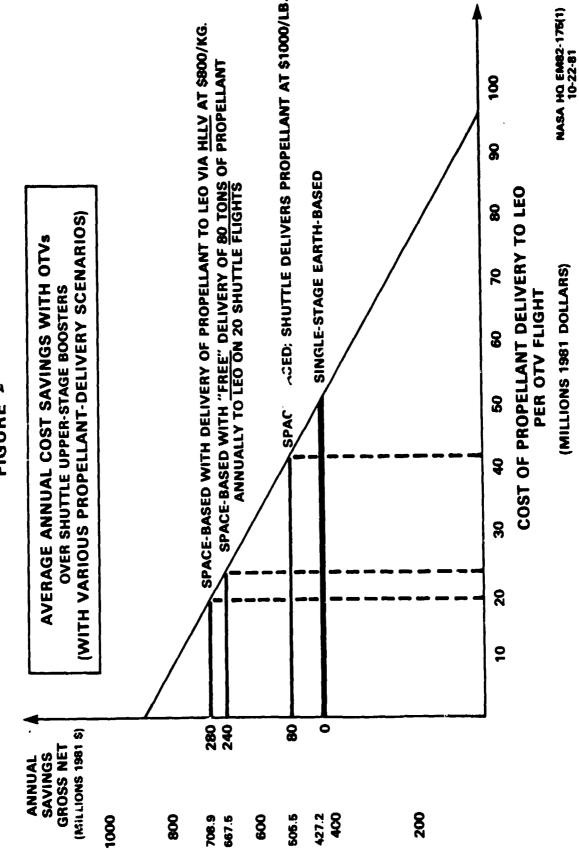| OPTION / PAYLOAD	SHUTTLE UPPER-STAGES	1-STAGE EARTH-BASED OTV	2-STAGE EARTH-BASED OTV	SPACE-BASED OTV
DELTA	17.2	22.5	42.8	20.3
ATLAS	26.7	22.5	42.8	20.3
IUS	96.3	45.0	85.6	40.6

AVERAGE ANNUAL COST SAVINGS (LOSSES)— USING OTVs, RELATIVE TO SHUTTLE UPPER-STAGE COSTS
(MILLIONS 1981 DOLLARS)

OPTION / PAYLOAD	ANNUAL FLIGHTS REQUIRED	1-STAGE EARTH-BASED OTV	2-STAGE EARTH-BASED OTV	SPACE-BASED OTV
DELTA	8.5	(5.3)	(217.6)	(26.4)
ATLAS	10.0	42.0	(161.0)	64.0
IUS	8.4	430.9	89.9	467.9
TOTAL SAVINGS (LOSS)		427.8	(288.7)	505.5

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FIGURE 2

AVERAGE ANNUAL COST SAVINGS WITH OTVs
OVER SHUTTLE UPPER-STAGE BOOSTERS
(WITH VARIOUS PROPELLANT-DELIVERY SCENARIOS)

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conservative assumption), the profit potential of the space-based
OTV system is reduced from over $500 million per year to under
$80 million.   Figure 2 summarizes the cost savings (i.e. maximum
profit potential) of the space-based OTV in comparison with the
Shuttle upper-stages and the Earth-based OTV.   Figure 2 also
illustrates the significance of the propellant delivery costs to
the SOC.   If the cost of delivering fuel to low Earth-orbit could
be reduced from $42 million to some lower cost, the SOC OTVs
would look much more attractive.   For example, if 80 tons of
propellant could be delivered to the SOC for "free" each year by
draining excess fuel from Shuttle external tanks, or by using
liquid oxygen as "ballast" in the Orbiter cargo bay, then the
profitability of the SOC OTV system could be increased by a
factor of three.   Another possibility shown in Figure 2 is
delivery of OTV fuel to the SOC by a heavy-lift launch vehicle
(HLLV), a Shuttle-derived "tanker" which reduces lift costs from
Earth by about 60%.   This would provide an even greater cost
advantage than the Shuttle fuel "scavenging" scenario.   A more
ambitious alternative is to process liquid oxygen from lunar ore,
which could reduce propellant delivery costs to $5 million per
OTV flight or less.   Since this is a highly speculative option it
is not included in this analysis, but it is conceivable that SOC
launch operations could provide sufficient economic justification
for the establishment of a lunar mining operation aimed at liquid
oxygen production.

Using the SOC as a base for the launch of communications
satellites could generate annual profits of $80 million to $280
million or more by the 1990s.   Although other SOC operations
would ultimately be expected to have even greater profit
potential, the SOC OTVs could provide financial stability and a
guaranteed income as the other SOC operations develop.   Another
basic operation which could be presumed to have profit potential
during early SOC operations is space science services.   The SOC
could play a vital role in the advancement of scientific research
in space, particularly in the area of life sciences.
Unfortunately, much of the SOC's value to space science is
qualitative, and is difficult to evaluate.   For example, how much
will it be worth to have the ability to conduct long-duration
studies of living systems on the SOC? How is this value
translated into SOC profit potential?   These questions are
further complicated by the fact that the government would
probably be a major consumer of SOC space science services.
We can, however, develop a simplified model of SOC space
science operations, and obtain a rough preliminary estimate of
the dollar value of such services.   Consider, for example, the
option of making the European Spacelab a permanent element of the
SOC design.   Aside from increasing the maximum duration for
Spacelab missions from one week to several months or years (a
tremendous benefit in itself), this set-up would have an obvious
economic advantage: the Spacelab module would not have to be
launched into space more than once, saving tens of millions of
dollars in transportation costs on Spacelab missions every year.
A SOC-Spacelab mission would require the launch only of

experiment racks and support personnel, which would require at
most one-third of a Shuttle flight. Integrating the experiment
racks into the Spacelab in space would be more complex than doing
so on the ground, but would cost only a tiny fraction of the $36
million which would be saved on every Spacelab mission by freeing
two-thirds of a Shuttle flight. Assuming 4-8 Spacelab missions
per year during the 1990s, savings on Spacelab transportaion
costs could range from $144 million to $288 million per year.
     In addition to transportation, there could be large savings
on daily SOC-Spacelab operations. The cost of operating the
Spacelab at the SOC would entail a relatively small marginal
increase in basic SOC operating costs, and could therefore cost
$200,000 to $500,000 per day less than operating the Spacelab in
the Shuttle cargo bay. If it is assumed that the Spacelab would
be in use at the SOC for at least 2 to 4 months per year, then
total savings on Spacelab transportation and operations could
range from $160 million to $350 million per year. Using the SOC
as a permanent base for the Spacelab would also represent a far
more efficient utilization of the Space Transportation System
than if the Shuttle had to be used for every day of Spacelab
operations.
     Many space science experiments will also have the potential
to lead to commercial applications of space technology. The
SOC-Spacelab would have an advantage over the Shuttle-Spacelab in
its provision of facilities for expansion to commercial-scale
space operations. For example, materials processing in space
experiments during the 1990s are likely to result in the
discovery of pharmaceuticals, electronics materials, and other
products for which zero-gravity space processing would be
economically advantageous. The SOC would have the space, energy,
manpower, and mission duration capabilities for commercial-scale
processing of many products that the Shuttle would not be able to
provide. The SOC would also serve as a base for space
construction, and could ultimately evolve into a full-scale
"space factory." Revenue from basic operations would not be
dependent upon such long-term developments, but the basic
operations could eventually lead to a SOC monopoly of space
manufacturing capabilities, which could be of enormous value.

IV. MILITARY OPERATIONS

     During the 1990s and beyond, military uses of space are
likely to expand as rapidly, if not faster, than civilian space
applications. It is almost certain that a manned station in low
Earth-orbit such as the SOC would be valuable, if not essential,
for national defense. This could turn out to be a positive
influence on the commercial viability of a SOC venture, but the
financial picture of SOC military operations needs much
clarification. Assuming that the military would be interested in
using a privately-operated space station, it is still very
difficult to assess the value of such operations to the SOC
ownership. This is primarily because of the secrecy involved in

the planning of future military space activities.

Launch of military payloads to geosynchronous orbit is a possible SOC service which could rival the launch of civilian communications satellites in financial importance. The Department of Defense (DOD) could also be presumed to have an interest in various types of space science activities, particularly those involving human beings in space for extended periods. Various reports have indicated that the military also has a profound interest in a manned "battle station" in space. (ref. 3). Its functions would include storage, servicing, and protection of military satellites; construction of large space systems such as power systems, particle-beam weapons, and energy shields; and manned coordination of military space activities. For these reasons it could be assumed that SOC revenue from military space operations could be as great as revenue from SOC basic operations, but for the purposes of this analysis it is also assumed that military SOC applications could be non-existent.

Even if the military were not willing or able to use a private SOC, however, its interest in space could indirectly help to make development of a private space station possible. The military could, for example, develop its own space station, and subsequently make the results of its DDT&E work available to the private sector. This would greatly reduce the cost of building a separate private space station, since as much as 85% of the cost of a facility such as the SOC would fall into the general category of research and development. One way in which the military and the private sector could share SOC costs would be for the DOD to pay a firm to design and develop a military space station, and for the firm to then build its own space station on the basis of the same R&D work. The second, commercial space station could perhaps be financed from profits made on development of the first (DOD) space facility. A private organization with an interest in establishing a SOC could pursue negotiations with military officials to assesss the possible role of the DOD in such cooperative activities. A financial picture of the SOC would be incomplete without thorough consideration of such alternatives.

V. SPECIALIZED OPERATIONS

Whereas basic operations and perhaps also military operations could provide a reliable source of income during the early years of SOC activity, there is a much broader range of specialized operations upon which the financial prospects of the SOC would ultimately depend. These specialized operations would make the SOC not only a focal point for space communications activities, but also for the development of space processing, space energy systems, and, in the long term, space habitation. It requires a bit of imagination to envision all of these as thriving industries, but the same was true of the now explosive space communications industry two decades ago. Not only would the SOC

have applications in all of these fields, but it could indeed be absolutely essential for the development of these industries. The owners of a SOC would have great influence over the development of these industries, as well as the financial benefits which could be realized through such pioneering endeavors.

As space activities continue to expand, demand for assorted launch services should increase. In addition to the basic operation of launching communications satellites, a SOC could be involved in the transfer of non-communications payloads to higher orbits. These could include remote-sensing and other science and applications payloads, as well as experimental structures, such as prototype satellite power systems. There would probably be a relatively small number of such payloads, since low-Earth orbit would suffice in many cases, but non-communications payloads could probably increase usage of SOC OTVs by 5-10% over that required for communications satellite launch services. This could represent an additional $4 million to $28 million per year in SOC profits.

Satellite servicing is another specialized SOC operation with a measurable profit potential. Despite the fact that communications satellites have relatively short operating lives (8-10 years), repairing, refurbishing, and upgrading these satellites in space could become an important SOC function. Estimates of the value of such services run as high as 40% of the total value of the satellite serviced, which is frequently in the tens of millions of dollars. Assuming a rather conservative profit of $2 million to $5 million per satellite serviced on ten to twenty such jobs per year, the SOC profit potential from satellite servicing can be calculated at $20 million to $100 million per year.

The most important specialized operation for a Space Operations Center, however, would almost certainly be materials processing in space. The profit potential from space processing during the 1990s and beyond is enormous, and, unlike other SOC operations, MPS has virtually unlimited growth potential. Unofficial industry projections of the gross annual sales of space-processed materials range as high as $50 billion by the end of this century. It can be safely stated that MPS is likely to be a key to the financial success of any SOC venture.

Unfortunately, it is impossible to verify estimates of the value of space processing. We are only beginning to understand the effects of zero-gravity on materials, and years of expensive research will be required before commercially viable space processing operations can be identified. NASA and industry have identified certain types of pharmaceutical products and electronics materials which may be significantly cheaper to produce in space than on Earth, and it is widely agreed that space processing will eventually become a thriving industry. But nobody knows exactly how or when.

A small number of companies have invested significant resources in MPS research, and some expect to begin commercial

space processing activities within this decade. Because of the high stakes involved, however, firms engaged in MPS are generally reluctant to publicize the results of their scientific and marketing research. McDonnell-Douglas Corp. (MDAC) has probably done the most to demonstrate the profit potential of space processing, but much of the company's work is shrouded in proprietary secrecy. MDAC has teamed with Johnson & Johnson to produce pharmaceuticals in space, and will begin flying experiments on the Space Shuttle as early as the summer of 1982. To date, tens of millions of dollars have been committed to this project by these two companies and by NASA (with whom a Joint-Endeavor Agreement has been signed), but it will still be several years before the commercial viability of these space processing operations can be proven. It may very well be worth the wait; annual sales of pharmaceutical products which are strong candidates for space processing are in the billions of dollars, and it can be safely assumed that MDAC is aiming for a significant share of this market.

Similarly, there are a number of electronics materials which have strong MPS potential. Space-processing of high-purity gallium-arsenide (GaAs) could revolutionize the electronics industry, and could generate a lively market for the product at several hundred thousand dollars per pound. In addition to pharmaceuticals and electronics materials, perfected glass products and exotic alloys might also be produced in space with results which could not be achieved on Earth, and at great profit.

There are few if any published estimates of the potential sales of space-manufactured products, but a survey of experts involved in MPS research would yield estimates of gross annual sales of space products in the range of $200 million (in 1990) to $50 billion (in 2000). This broad range of estimates illustrates the great degree of uncertainty with regard to the future of commercial MPS, but also demonstrates clearly a high level of confidence in the potential of space processing. For the purposes of this analysis this range can be narrowed to a more or less conservative $1 billion to $6 billion in gross annual sales as a 1990s average. If 20% of MPS sales could be allocated as "rent" to the SOC, then the SOC revenue potential from space processing would be in the range of $200 million to $1.2 billion per year by the mid-1990s.

Despite the uncertainties involved, it is evident that MPS could become the single most profitable SOC operation by the end of the 1990s. With continued growth in commercial space processing applications, the Space Operations Center could ultimately evolve primarily into a space factory, regularly shipping a wide variety of important medical and industrial products to Earth. Ground-based MPS research and small Shuttle experiments over the next several years should help to resolve the uncertainties involved in commercial space processing, and should also help to clarify the SOC financial picture.

VI. SOC REVENUE SUMMARY

The revenue projections for SOC operations are summarized in Table 5. Many possible SOC operations, such as space construction, are not included because of the difficulties involved in evaluating their profit potential. Those figures which are listed, however, are certainly open to debate as well. Many assumptions went into the formulation of these estimates, some of which are presented in Table 6, the SOC sensitivity analysis. Here the impact of a 50% cahnge in the assumed or mid-range values of SOC operations and underlying assumptions are listed. For example, a 50% change in the mid-range value of military operations ($315 million/year) results in a 10% change in SOC revenue. Similarly, a 50% change in the assumed demand for communications satellite launches (estimated to require 100 OTV flights from 1990 to 2000) causes a 6% change in SOC total revenue. The value of the sensitivity analysis is that it shows which SOC operations are most important to study in order to develop a more firm financial assessment of a SOC enterprise.

VII. SOC COSTS

Determining the cost of a Space Operations Center, although a formidable task in itself, is somewhat less risky than attempting to predict the profitability of SOC operations. Experience with Skylab, Spacelab, and previous generations of launch vehicles has provided a basic understanding of the major costs involved in the development and utilization of orbital space facilities, and the level of costs associated with the SOC would probably not be out of line with that of other large projects of the past. In fact, the SOC would probably cost only a small fraction of what Project Apollo cost (10-20%, at most), and less than half of what NASA has already invested in the Space Shuttle.

NASA is currently sponsoring in-depth studies of SOC costs, but fairly detailed first-order estimates have already been achieved. For a full "growth" SOC capable of the types of operations described in th's paper, total development and production costs have been estimated at between $5 billion and $7 billion, with the actual hardware production costs accounting for only about $1 billion of this total. The major contributors to SOC costs are DDT&E for the SOC habitat and service modules, systems testing and evaluation, and program support, which together comprise about half of the total. These cost estimates, however, are based on the assumption that NASA will be the builder and operator of the SOC. If the SOC were built by a private company, a total cost reduction of about one-third would not be an unreasonable expectation. Possibilities also exist for the reduction of SOC costs through simplification of the SOC design and utilization of existing hardware. A SOC fabricated from the Shuttle's external fuel tanks, for example, could greatly reduce the costs of the expensive habitat and service modules. Such possibilities need to be investigated thoroughly

TABLE 5

SOC REVENUE SUMMARY

			LOW	HIGH
BASIC OPS.	COMMUNICATIONS SATELLITE LAUNCHES	COST ADVANTAGE OF SOC OTVs OVER BEST COMPETITOR, 1-STAGE EARTH-BASED OTV. VARIANCE DUE TO PROPELLANT COSTS.	$ 80	280
	SPACE SCIENCE	$36M COST SAVING PER "SPACELAB-EQUIVALENT" 1-WEEK MISSION, PLUS SAVINGS ON EXTRA-DAYS ON ORBIT. 4-8 WEEKS/YEAR.	160	350
		SUBTOTAL	240	630
SPECIAL OPS.	MILITARY OPERATIONS	COULD RANGE FROM 0 TO 100% X BASIC OPERATIONS	0	630
	NON-COMMUNICATIONS SATELLITE LAUNCHES	REVENUE IS 5-10% OF THAT DERIVED FROM LAUNCH OF COMMUNICATION SATS	4	28
	SATELLITE SERVICING	10-20 JOBS/YR @ $2-5M EACH	20	100
	SPACE PROCESSING	20% OF GROSS ANNUAL SALES OF SPACE PRODUCTS	200	1200
		TOTAL	464	2588

TABLE 6

SENSITIVITY ANALYSIS

OPERATIONS

	ASSUMED OR MID-RANGE VALUE	50% CHANGE	IMPACT OF 50% CHANGE ON SOC REVENUE
1 COMMUNICATIONS SATELLITE LAUNCHES	$180M	$ 90M	6%
2 SPACE SCIENCE	$255M	$128M	8%
3 MILITARY OPERATIONS	$315M	$158M	10%
4 NON-COMMUNICATIONS SATELLITE LAUNCHES	$ 16M	$ 8M	½%
5 SATELLITE SERVICING	$ 60M	$ 30M	2%
6 SPACE PROCESSING	$700M	$350M	23%

ASSUMPTIONS

|	ASSUMED OR MID-RANGE VALUE	50% CHANGE	IMPACT OF 50% CHANGE ON SOC REVENUE
1 COST PER FLIGHT—SOC OTVs	$81.1M	$40.6M	18%
COST PER FLIGHT—EARTH-BASED 1-STAGE OTV	$ 90M	$ 45M	19%
PROPELLANT DELIVERY COST/FLIGHT	$30.7M	$15.4M	9%
DEMAND FOR COMM. SAT. LAUNCHES (OTV FLTS REQ)	100	50	6%
2 SAVINGS ON SPACELAB TRANS. COSTS (PER MISSION)	$ 36M	$ 18 M	7%
NUMBER OF SPACELAB MISSIONS/YR.	6	3	7%
4 DEMAND FOR NON-COMM. SAT. LAUNCHES (PERCENT OF COMM. SATS.)	7.5%	3.8%	½%
NUMBER OF SATELLITE-SERVICE MISSIONS/YR.	15	8	2%
5 COST SAVINGS PER SERVICE	$ 3.5M	$ 1.8M	2%
GROSS ANNUAL SALES OF SPACE PRODUCTS	$ 3.5B	$ 1.8B	23%
6 PERCENT OF GROSS ANNUAL SALES AS SOC REVENUE	20%	10%	23%
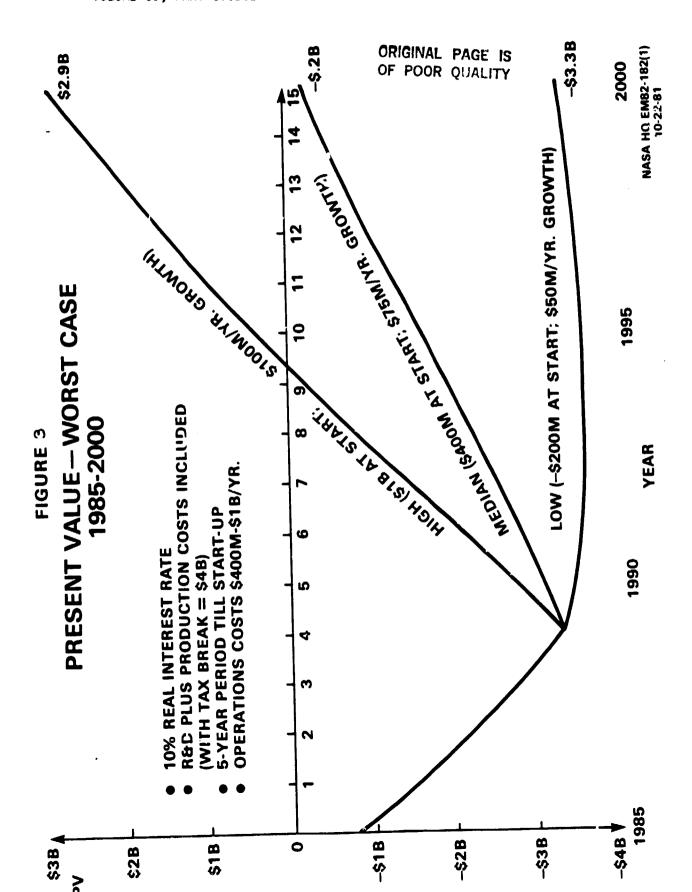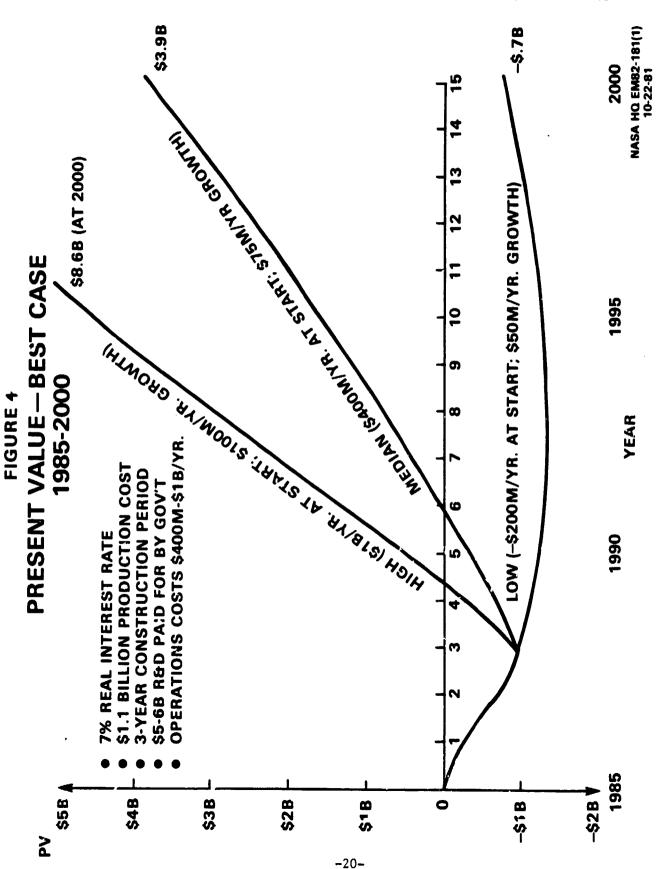
before a committment is made to full development of any
particular SOC design.

    In addition to development and production costs, there would
be basic costs involved in the support of the SOC crew and
operations. A very rough estimate of these SOC operating costs
is $400 million to $1 billion per year, which corresponds to
approximately $1 million to $3 million per day. These costs
would obviously increase with the expansion of SOC activities,
but for the operations described in this paper over the given
time period (1990-2000), it is unlikely that baseline operating
costs would exceed $1 billion per year. It should be emphasized,
however, that these figures do not include variable costs
associated with particular SOC operations, such as OTV costs
(previously estimated at about $31 million per OTV flight) and
the costs associated with changing Spacelab equipment and
personnel ($20 million minimum per mission). These variable
costs, however, are accounted for in the SOC revenue model;
revenue from communications satellite launch services, for
example, is calculated as the net difference between the variable
cost associated with operation of the SOC OTVs, and the cost of
launching communications payloads with other systems (e.g.
Shuttle upper-stage boosters).

                    VIII. SOC PRESENT-VALUE ANALYSIS

    One method which can be used to evaluate the attractiveness
of the SOC as a private business venture is to perform a
discounted present-value analysis. Figure 3 shows a "worst-case"
present-value assessment for private SOC financing. Through a
combinat n of tax credits, design modifications, and
private-sector efficiency the actual undiscounted investment
required is reduced from the estimated $5-7 billion required for
the NASA SOC (ref. 4) to $4 billion. This is not an overly
optimistic assumption. The analysis also assumes a real discount
rate of 10%, a pessimistic assumption, and covers a five-year
development period and the first decade of SOC operations. Based
on the SOC revenue and cost models presented in this paper, three
separate scenarios for the growth of SOC operating revenues are
considered. On the high side, SOC profits begin at $1 billion
per year and grow at the rate of $100 million per year. On the
low side, the SOC starts off by losing $200 million per year, and
improves at the rate of $50 million per year. In the median
case, the SOC grows at a rate of $75 million per year following
initial annual earnings of $400 million per year. The discounted
present-value of the SOC enterprise, evaluated in the initial
year, is measured on the vertical axis. The horizontal axis
represents the duration of the investment horizon. If the median
growth rate for SOC earnings were achieved, for example then the
estimated present-value of the first ten years of the enterprise
would be about -$1.6 billion. With the investment horizon
extended to fifteen years (through the year 2000, in this
example), the present-value would be approximately -$0.25

FIGURE 3

PRESENT VALUE—WORST CASE
1985-2000

- 10% REAL INTEREST RATE
- R&D PLUS PRODUCTION COSTS INCLUDED
- (WITH TAX BREAK = $4B)
- 5-YEAR PERIOD TILL START-UP
- OPERATIONS COSTS $400M-$1B/YR.

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FIGURE 4
PRESENT VALUE—BEST CASE
1985–2000

- 7% REAL INTEREST RATE
- $1.1 BILLION PRODUCTION COST
- 3-YEAR CONSTRUCTION PERIOD
- $5-6B R&D PAID FOR BY GOV'T
- OPERATIONS COSTS $400M-$1B/YR.

$3.9B

$8.6B (AT 2000)

(HIGH)

HIGH ($1B/YR. AT START; $100M/YR. GROWTH)

MEDIAN ($400M/YR. AT START; $75M/YR GROWTH)

LOW (-$200M/YR. AT START; $50M/YR. GROWTH)

-$7.7B

PV

$5B
$4B
$3B
$2B
$1B
0
-$1B
-$2B

1985   1990   1995   2000

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

YEAR

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-20-

billion. In this assessment the present-value of the SOC ranges
from a loss of $3.3 billion to a gain of $2.9 billion. It should
be noted that with an assumed 10% real discount rate, a
significant risk expectation has been included in the analysis.
The payback period in this worst case ranges from ten to twenty
years.

Figure 4 shows a present-value analysis based on a set of
more optimistic (and probably more likely) conditions. In this
case it is assumed that through some type of joint private-public
endeavor, the private investment is limited to the $1.1 billion
SOC production cost, and that SOC operations begin after a
three-year investment period. The most likely means of achieving
a SOC through this level of private financing would be for NASA
or the DOD to fund SOC research and development, and for the
private sector to become involved at the conclusion of such
efforts, financing only the actual construction of the facility.
There are, however, other possible means of reducing private
outlays to the $1 billion-range, including the earlier-mentioned
options of tax credits and cost-saving design modifications.
This "best-case" present-value scenario also assumes a real
discount rate of 7%. The growth of SOC earnings is considered in
the same three cases as the "worst-case" present-value analysis.

The results of the best-case present-value analysis are
striking. Present-value ranges as high as $8.6 billion, with
payback periods as short as 5 years. Even the low-growth
scenario results in a positive present-value if the investment
horizon is extended slightly beyond the year 2000, and the median
case yields a present-value of nearly $4 billion. Why then, are
private companies not stampeding to work with the government to
develop a privately-operated multi-purpose Space Operations
Center? There are three major reasons. First, these cost and
revenue projections are all very "soft" and will require large
expenditures of resources for confirmation. Second, the
companies most qualified to undertake such a venture (such as
aerospace and defense firms) have a vested interest in working
through more traditional channels, and the concept of a
privately-financed SOC will take some time to gain acceptance in
the industry. Finally, companies (and non-aerospace firms in
particular) tend to view all space projects as enormous,
long-term, high risk investments, and if the SOC is an exception
to this rule (which it may or may not be) it can be proven only
at considerable expense.

The Space Operations Center is an exciting concept whose time
may be coming. It may happen within this century, or it may take
awhile longer to develop. While there is a broad spectrum of
financing alternatives which might be applicable to the
development of such a facility, the figures in this paper
demonstrate that there is a chance that a SOC could be developed
privately or semi-privately at a considerable profit, with the
potential for particularly impressive long-term financial
returns. Although this study is not in itself justification for
such a venture, it does, in the author's opinion, present a set
of fascinating business opportunities which merit careful
consideration.

Appendix A - Decision Trees

The present value assessments performed in section VII
considered only two of many possible financing alternatives for
development of the Space Operations Center. SOC financing
options can also be viewed in the context of a decision tree,
which goes a step beyond calculation of discount rates in the
evaluation of project risk. In the decision tree in Figure 5,
the branches 1 through n emanating from the decision node D
represent distinct SOC financing alternatives, and are hence
"decision variables." Decision branch 1, for example, could
represent a case in which the SOC is financed solely by private
funds, which would be partially analagous to the "worst-case"
present-value scenario in section VII (Figure 3). Decision n, at
the other extreme, might represent a case in which the SOC is
financed in full by the government.
     Each financing alternative has associated with it a range of
possible outcomes with regard to SOC value and earnings.
Included among the outcomes for decision 1 might be the high,
median, and low SOC earnings outcomes associated with the
worst-case SOC financing scenario. In the SOC present-value
analysis in this paper these outcomes were treated as discrete
(distinct) growth rates for SOC earnings, each representing a
particular present-value. The present-value associated with
branch 1b in Figure 5, for example, would be the median growth
scenario for the worst-case financing alternative, or -\$0.2
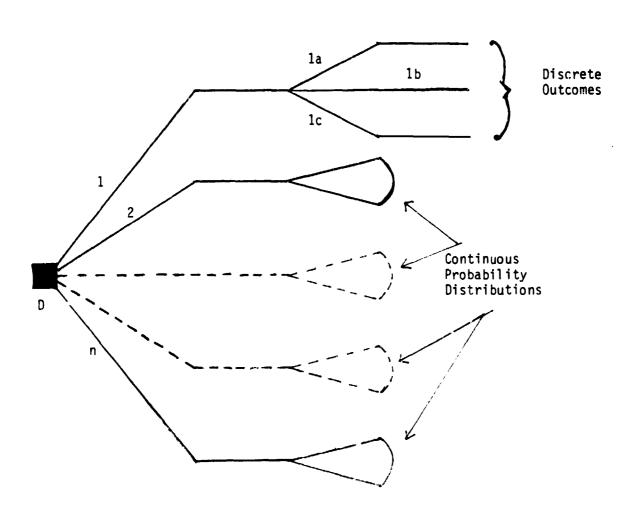billion.
     A vigorous comparative study of the values of various SOC
financing options would have to attach many more than three
possible value outcomes to each SOC financing alternative. In
fact, discrete value outcomes might be discarded in favor of
"continuous" distributions on earnings. For (undefined)
financing alternative 2, for instance, present-value could
perhaps range from -\$2 billion to \$2 billion, with an infin···
number of possible value outcomes in between. To calculate the
probability of attaining any particular present-value within this
range would require knowledge of the "probability distribution"
over SOC earnings for that financing option. A more thorough
study of SOC financing alternatives would also have to better
define SOC "present-value" and "earnings." In this paper, the
value of the SOC was viewed primarily from the perspective of a
private company engaged in a SOC enterprise, hence present-value
was calculated in terms of dollar profit and was of course higher
for the case in which much of the SOC financing was undertaken by
the government. If instead total "social" costs and benefits
were taken into account, the differences between the "best-" and
"worst-case" present-value scenarios might not have been as
great.
     The final goal of the decision-tree analysis would be to
associate with each SOC financing alternative a range of possible
value outcomes and a probability distribution over each range.
This would permit the calulation of the "expected value" of each

financing alternative, and the option with the greatest expected value could then be selected. As was just mentioned, however, judgment of the relative merits of each financing alternative would depend greatly on how SOC "value" is defined to begin with.

FIGURE 5

A Decision Tree for Various SOC Financing Alternatives

Appendix B - SOC Military Operations

In discussing SOC military operations, it is not the author's
intent to advocate the militarization of space. The major
purpose of this paper, in fact, is to explore possibilities for
the rapid growth of peaceful applications of space technology.
It should be recognized, however, that military uses of space can
and have aided world stability by providing reliable
communications systems, verification of compliance with arms
control treaties, and the security which comes with knowing what
other nations are doing militarily. It is hoped that it is these
military operations which will be continued, rather than the
development of space weapons systems which could undermine
international stability and the balance of power. In order to
prevent the latter possibility from becoming reality, it is the
author's opinion that terrestrial and space arms control
negotiations should be pursued vigorously, and that all civilian
and military uses of the SOC and other space facilities should be
carefully designed to enhance, rather than to weaken, the cause
of world peace.

Notes

1. Future Systems Inc., "Forecast of Space Shuttle Requirements for Launch of Commercial Communications Satellites," September 6, 1977.

2. NASA in-house estimates, Johnson Space Center, October 1981.

3. New York Post, Monday October 5, 1981, page 2.

4. Boeing Aerospace Company, "Space Operations Center - System Analysis: Final Briefing, June 25, 1981.

PRIVATE FINANCING AND OPERATION OF A SPACE STATION:
INVESTMENT REQUIREMENTS, RISK, GOVERNMENT SUPPORT, AND
OTHER PRIMARY BUSINESS AND MANAGEMENT CONSIDERATIONS

Michael Simon
September 1982

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appears likely to achieve an initial "permanent manned presence" in space

by the end of this decade. Although the government would play an active

role in the development of any space operations base, private investment

in a manned space station may represent a viable alternative to complete

government sponsorship of such a program. Since private-sector interest

in space stations is likely to increase as the public strengthens its

commitment to maintaining a manned presence in space, it is desirable that

NASA and other government agencies understand the implications of manned

space operations from a business perspective. This report outlines the

most significant problems which would be faced by a private company

involved in a space station enterprise, and suggests possible government

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agencies understand the implications of manned space operations

from a business perspective. This report outlines the most

significant problems which would be faced by a private company

involved in a space station enterprise, and suggests possible

government roles in helping to overcome these difficulties.

I. Introduction

The expected need for a permanently-manned space station by
the end of this decade presents an intriguing opportunity for
American industry. The first company or companies to own and
operate a space station could be in a position to play a
leadership role in all aspects of space industrialization, a
high-technology field of emerging importance. A space station
could play a pivotal role in the development of space
communications and materials processing in space, both of which
are expected to become multi-billion dollar industries by the
1990s, and might also have business applications in the areas of
life science, space energy and transportation systems, and space
defense systems. These activities could represent a combined
profit potential of close to $3 billion annually in space station
support services by the end of this century.[1]

The barriers to commercial investment in a space station,
however, are formidable. Judged by almost any commonly accepted
business standard, a space staion would be a high-risk venture
with potential for large financial losses. Such an endeavor
would also raise a wide range of sensitive political and social
issues, creating unique problems which would require equally
visionary solutions. For a vast majority of free-market players,
these barriers are sufficient to discourage any large investment
in a manned space station.

For these reasons it is unlikely that a space station could

be built without considerable support from the government. This

raises still another important issue: to what extent should the

government provide incentives to attract private investment in

space projects? While on the one hand space is being touted as

the site of an impending "third industrial revolution," it is

also true that premature development of space resources by the

private sector could have serious adverse consequences. The

argument for private investment in space is that it will help to

establish an industry which is sensitive to actual market

conditions, i.e., the needs of the people. Yet if the government

steps in to make such investment possible, the industry which is

spawned could be more responsive to the government incentives

than to the underlying reasons for the incentives. A period of

rapid, artificially stimulated growth could thus be followed by

stagnation and continued dependence on government intervention.

The railroad and automobile industries are excellent examples of

this unfortunate phenomenon.[2]

This report will not fully answer the question of whether

the government should actively stimulate private investment in

space. It will, however, take a necessary first step in this

direction by defining the barriers to investment, and suggesting

steps the government might need to take in order to reduce these

obstacles. Before we attempt to decide what the government

should do to increase the attractiveness of space investments, we

must understand the bases on which such investment opportunities

are judged. This will lead to a recognition of those relevant

actions the government is capable of taking to encourage such

investments, a requisite understanding for deciding if such

actions are warranted.

Investment Considerations

Most business opportunities are judged according to three

primary considerations. These are the amount of money invested

and recovered, the expected time over which the returns accrue,

and the level of risk in the investment.[3] Although the primary

attraction of the space station is its potential for large

economic returns, particularly in the long-term, the investment

required would also be tremendous, perhaps as great as for any

single privately-financed project in American history. Estimates

of the total cost of a space station range from $2 billion to

over $20 billion, depending on the configuration of the facility

and the mode of financing.[4] Even at the lower end of this range,

the financial liability involved in such a venture would be

enormous.

On the basis of the second investment parameter, investment

horizon (also referred to as "payback period"), the space station

investment opportunity is equally suspect. Space operations

would probably not begin to generate revenue until five to ten

years after the initial investment in the space station, and

investment recovery ("break-even") would probably take at least

ten to fifteen years. By comparison, most venture capitalists

require not only economic recovery, but an extremely high return

on their investment, within a period of three to five years.[5]

Expectations of paybacks two or three times the size of the

initial investment within a period of five years or less, are not unheard of in the venture capital industry.

The greatest obstacle to private financing of a space station, however, is risk. There are five major types of risk associated with large investments: technical risk, market risk, financial risk, institutional risk, and business risk.[6] With regard to four of these five factors (business risk is detrmined by internal organizational characteristics and will not be considered here, the other four factors will be discussed in greater detail in Section III) a space station enterprise could only be characterized as a high-risk venture. Although there are many actions a company could take to minimize risk (whereas investment level and payback period are relatively fixed requirements), the high levels of perceived and actual risk involved in a space station enterprise are the most critical factors to be dealt with in order to make such a project commercially feasible.

In addition to these "investment-specific" factors, there are other general conditions which could influence the prospects for success in a space station investment. These include primarily economic factors such as inflation and the rate of interest, and also include such less obvious conditions as anti-trust and appropriate regulatory laws, government appropriations for space activities, and national security considerations. The following three sections provide more detailed discussion of all of these factors, as well as recommendations on how the government can act to reduce the dissuasive effect of these factors on private investment in space operations.

II. Space Station - Investment Level and Investment Horizon

The most obvious deterrent to private financing of a space
station is the enormous cost which such a project would entail.
The multibillion dollar price tag of a space station would exceed
the average venture capital investment of one to two million
dollars by a factor of several thousand,[7] and could even rival
the $10 billion cost of the trans-Alaska Pipeline, the most
expensive privately-financed project to date. Even if there were
very little risk involved in such a venture, financing of a
manned space facility by private sources would represent an
unusually bold and complex business enterprise, which would
require new and innovative government/industry relationships.

It is difficult to pinpoint the minimum investment which
would be required to initiate profit-making space operations.
Space station cost estimates made by NASA and other government
agencies do not necessarily reflect the levels of investment
which would be required if such a project were built privately,
since the mode of financing has a significant impact on project
cost. Recent NASA estimates of space station costs can be
useful, however, in developing first-order assessments of
investment requirements.

The least expensive design concept under consideration at
NASA is the "minimum space station," estimated to cost about
$2 billion. As its name suggests, however, the minimum space
station would be a relatively simple and limited facility.

Consisting only of a small three-man habitation module and perhaps one or two other small compartments for science experiments, the minimum space station would have little, if any commercial value. A space station capable of generating sufficient revenue to turn a profit would probably more closely resemble the 8-man "Operational"-phase Space Operations Center (SOC), which Boeing has estimated would cost NASA about $8.0 billion.[8] The Operational SOC would include logistics and service modules for space science experiments and materials processing, and facilities for basing at the SOC a fleet of reusable chemical-propulsion orbital transfer vehicles (OTVs). The OTVs would carry payloads from the low-orbit SOC to higher orbits, and might generate substantial revenue by delivering communications satellites to geosynchronous orbits. The SOC-OTVs could also be involved in the potentially lucrative business of satellite-servicing and retrieval. Although satellites become obsolete relatively rapidly, retrieval and reuse of expensive satellite components could be highly cost-effective.[9]

At present these appear to be the most marketable services which a space station could provide. A space station could provide space science services, for which the government would be a primary consumer, with greater capabilities than the Shuttle-Spacelab configuration, and at a lower cost. Space station materials processing capabilities could be attractive to certain private users, such as McDonnell-Douglas Corporation, which anticipates the development of a multi-billion dollar market for space-processed pharmaceutical products by the 1990s.

A fleet of reusable OTVs based at a space station might provide
launch services marketable in both the public and private
sectors.   On the order of five hundred communications satellites
may be launched into geosynchronous orbit over the next twenty
years, and theoretically nearly all could be placed in their
proper orbits via space-based OTVs.   The government, in
particular the Department of Defense, might also require launch
capabilities to geosynchronous orbit which could be provided by a
space-based OTV fleet.

     With the cost of the Shuttle flights required for deployment
of the SOC included, the total investment required for achieving
the operational capability just described would be about $6-10
billion, spread out over a five to ten year period.   Clearly the
magnitude and timing of this investment limit the range of
possible participants in a space station venture.   If the
Operational SOC were developed privately, the costs and
investment horizon could perhaps be reduced significantly by
circumventing bureaucratic regulations and inefficiencies
frequently associated with large government projects.   In such an
optimistic case, however, the investment requirements would still
be prohibitive by any business standard.   Even at $3 billion, for
example, a fully operational space station would still be beyond
the means of most private investors, and nearly a hundred times
more expensive than the largest venture capital enterprise ever
undertaken.[10]

     Although a fully private undertaking of such a venture
cannot be completely ruled out, it is almost certain that the

government would in some sense have to be a "partner" in such an
enterprise. In fact, there are numerous incentives which could
be provided by the government to reduce space station investment
requirements, perhaps to within acceptable ranges. NASA could,
for example, develop a space station "core," consisting of
habitation modules, solar power arrays, and communications
equipment. A private company could then add to the space station
core the specific facilities required for doing business in
space. A space science module could perhaps be added at a cost
of $500 million to $1 billion. A commercial materials processing
facility might be provided for half as much. Development of an
OTV and OTV support equipment could probably be achieved
privately for $1-1.5 billion. A company could therefore provide
services on a space station for an investment as small as 5-10%
($500M/$10B = 5%) of the cost of a full NASA space station.
Thus, the cost of developing these service capabilities
independently are well within the means of private investors.

Another joint-venture scenario might call for the government
to perform the research and development required for a space
station, with private companies responsible for production and
operation of the station. Contractors could perhaps finance
production of some of the required space station hardware with
profits earned by designing the components for NASA. In exchange
for sponsoring the initial design and development, NASA might
require owner-operators of the space station to provide services
to the government at a reduced rate. Such an arrangement could
reduce space station investment requirements to acceptable levels

because the actual hardware production would comprise only about 30-50% of the total space station cost.[11]

Joint public-private ventures of this nature would raise a number of new policy problems for the government, but through its Joint-Endeavor and other programs NASA has demonstrated an ability and willingness to work with private companies toward common goals in creative ways. Joint arrangements for space station development could be attractive from the government's viewpoint because they might reduce the appropriations required to establish manned space operations. This would free funds for space station utilization; a major problem with the Space Shuttle is that its high development costs have limited NASA's ability to design uses for it. (The Space Shuttle presently consumes nearly two-thirds of NASA's research and development budget[12]). Moreover, private investment in a space station could be a significant first step toward the establishment of a new, space-based industry with a large tax base and other social benefits. Reducing the investment requirements for space station operations to acceptable business levels might therefore be within the means and in the interests of the U.S. Government.

III. Space Station - Risk

Risk is by far the greatest impediment to private investment
in a space station. The high cost of a space station could be
considered acceptable for investment purposes if the risks
involved in such a venture were sufficiently small. As mentioned
earlier, the degree of risk in a space station venture is
tremendously high with respect to the four major types of
investment risk considered here: technical risk, market risk,
financial risk, and institutional risk. It is almost certain
that the government's assistance would be needed in order to
reduce the risks in a space station enterprise to acceptable
business levels.

This dependence on the government, however, would in itself
represent a significant risk; as a partner in a long-term space
station enterprise the government would be highly suspect. For
example, a government delay in providing expected support during
space station development, such as NASA's two-year delay in
developing the Space Shuttle, could spell disaster for the
private partners in such a venture. A change in presidential
administrations, or a key NASA personnel change, could also
adversely affect the government's ability to follow through on
such a long-term commitment. For reasons such as these, any
joint private-public venture would need to be backed up by firm
agreements, where all parties (including the government) would be
legally bound to meet their obligations. Special legislation

might even be required to ensure the availability of government
funds for the duration of the project. From the viewpoint of any
private partner, the government's involvement in a space station
enterprise would paradoxically be necessary for reducing risks,
but also a substantial risk in itself. This chapter deals with
many of the types of risk which would be involved in a space
station venture, and the ways in which the government might need
to be involved in order to diminish these risks.

Technical Risk

Technical risk involves all uncertainties with regard to how
well a product will function. A space station involving
thousands of complex technological components functioning in a
hostile and unforgiving environment would entail possibly the
greatest technical risk of any private project ever undertaken.
Not only would the possibilities for technological, scientific,
or human failures be great, but the costs associated with such
breakdowns could also be enormous. Particularly in a private
space enterprise, the temptation to cut costs and achieve quick
results would be great, exacerbating the problem of technical
failure.

Through its ongoing research and development programs the
government is constantly working to reduce the technical risks
which such projects usually entail, and the benefits of this
baseline work would almost certainly be available to private
organizations involved in a space station enterprise. Beyond
this, the government could set up a program within NASA to assist

the private sector in evaluating and overcoming the technical

risks involved in early space operations. Such a program could

help transfer technical knowledge and expertise from NASA and

high-technology industries to a broader cross-section of

potential investors, with the specific goal of maximizing the

private sector's contribution to (and benefit from) manned space

operations. Such a program would probably be most effective in

providing potential investors with an initial basic familiarity

with space investment opportunities, since investors with limited

technical expertise or R&D facilities would probably ultimately

contract development work out to better-equipped companies such

as aerospace firms.

Market Risk

Whereas technical risk is the risk associated with creation

of a product or service (supply), market risk is the risk

involved in selling a product (demand). The development of any

commodity or service is always preceeded by some type of market

analysis to define such factors as total product demand, price

sensitivities, product distribution, and advertising. The market

risk which would be involved in developing space operations is

particularly acute because of the possible emergence of competing

alternative technologies. During the long lead-time preceeding

the operating life of a space station, other means of

accomplishing the space station's intended tasks could be

developed. NASA's Materials Processing in Space program has

demonstrated, for example, that improved ground-based processes

may frequently compete effectively with space processes. This could also happen in other areas critical to the success of a space station, such as space transportation. During the long development time of the Space Shuttle, the European Space Agency developed a strong competitor for commercial launch services: the Ariane expendable launch vehicle. Since materials processing and space transportation could be two of the major services which a space station would provide, these examples are particularly meaningful.
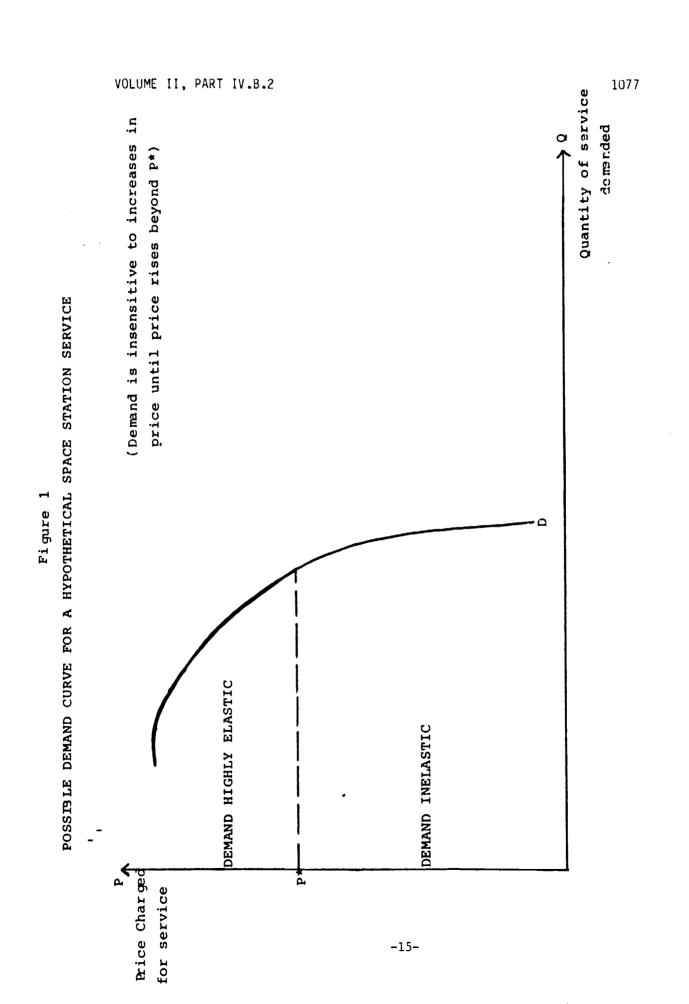
The possible emergence of competing ground-based technologies is only one of many important elements of space station mission modeling and marketing which require extensive further study. Previous studies of space station uses have focused almost exclusively on technological capabilities, without ever addressing the question of who would pay for space station services. This is perhaps because it is exceedingly difficult and risky to forecast demand functions for commodities and services which do not yet exist.

Another type of market risk which should be examined regards the ability of users to pay for space operations. In the absence of competing technologies, the demand for space station services might be fairly inelastic over a certain price range (i.e. not very responsive to changes in price), but at some point demand could suddenly drop dramatically given any additional price increases. The advantage of manufacturing certain high-value products in space, for example, might be so great that relatively large increases in the cost of space processing would not deter

investors from using a space station's processing facility. As the cost of space production increases, however, a point may be reached beyond which Earth-based processes are more economical. (See Figure 1). In the case of such revolutionary services as space operations, it is particularly difficult to determine where such break-points in product demand will occur.

The government might play a key role in reducing market risk by essentially guaranteeing a market for certain space station services. Obviously NASA has a strong interest in utilization of such a facility or the space agency would not be considering the development of a space station as a major new project. Instead of developing a station on its own, NASA could agree to use a private space station for space science services, for example, and promise to pay a certain sum of money to the space station operators annually. Use of a space station for science could possibly save the government several billion dollars over an extended period, so the value of such a market guarantee to the government could be considerable.[13] Similarly, the government could agree to utilize other space station services, such as OTV flight support for NASA payloads.

Contracting to "rent" the services of a privately-owned space station as needed might be more cost-effective for the government than building and operating the entire space station, and would eliminate a large degree of market risk for the private owners. Although such a market guarantee would raise legal issues concerning government procurement practices and creation of monopoly conditions, there are precedents for such

Figure 1

POSSIBLE DEMAND CURVE FOR A HYPOTHETICAL SPACE STATION SERVICE

(Demand is insensitive to increases in
price until price rises beyond P*)

DEMAND HIGHLY ELASTIC

DEMAND INELASTIC

Price Charged
for service

Quantity of service
demanded

government-guaranteed markets, most notably the Terrestrial Data
Relay Satellite System (TDRSS). The TDRSS was developed
privately and will be leased by NASA for a ten-year period
beginning in 1983 for approximately $2.3 billion.[14]

From the perspective of a private space station operator,
government use of a space station could present another marketing
problem. The government would probably desire priority over
other space station users during times of national emergency; the
possibility of such a government "priority override" might create
problems for commercial users. This is another issue regarding
government support and use of privately owned space facilities
which requires further study.

Financial Risk

Financial risk, another important element of risk in
business ventures, is the uncertainty pertaining to the
investment level and payback period. These aspects of a space
station venture, which were discussed in the previous section,
represent a high degree of perceived risk for such an endeavor,
primarily because of the enormous up-front investment which would
be required before any profits could be realized. In the case of
a space station, financial risk would also include the great
ranges of uncertainty regarding development and operating costs,
which in such high-technology projects often exceed initial
expected by large margins. Financial risk would also be
exacerbated by the long lead-time preceeding actual space station
operations. In one sense, however, the space station venture

fares favorably with regard to financial risk. The very high long-term potential for financial gain is a primary reason that businessmen may ultimately be willing to face the risks involved in a space station venture.

The government's role in reducing financial risk would probably be limited. Financial risk is a primary "acid-test" for investment opportunities, since it bridges the requirements of investment level and risk management. The government could only influence financial risk by altering the nature of the business task itself, i.e., by sharing the cost of building a space station with the private sector. By developing a space station core, for example, the government might substantially reduce the amount of hardware a company would have to provide, and hence the investment required for initiating marketable space operations.

Institutional Risk

The most critical area of government involvement in a private space station enterprise would be with regard to institutional risk. This is the risk associated with the logistical support services and equipment necessary to carry out a designated task. Institutional risk also encompasses a broad spectrum of uncertainties with regard to the economy, legal rulings, taxes, the availability of government support, and other factors. Institutional risk is in fact the one area in which government cooperation, or at the very least non-interference, is essential to the success of a private space station venture.

As a major example, it would be the government's duty to

ensure the availability of the Space Shuttle flights required for

space station deployment, support, and operations, since NASA is

the sole operator of the Shuttle. Uncertainties regarding the

availability and cost of Shuttle flights are in fact often cited

as primary factors in the reluctance of businessmen to become

involved in space development. NASA's Joint-Endeavor program,

which offers free Shuttle flights and other services to companies

which are willing to explore new markets for space products, has

to date attracted only three industry participants. A primary

reason for this is that in Joint-Endeavor Agreements NASA can

only promise to use its "best efforts" to meet the industry

participant's Shuttle flight requirements.[15] Maintaining an

affordable and reliable fleet of operational Shuttle Orbiters,

one of NASA's major agency goals of this decade, will be critical

to the management of institutional risk in all types of space

endeavors.

Government tax incentives (and disincentives) could also

play a great role in determining whether a space station project

would represent an acceptable risk to the private sector.

Although the government would expect space-based industries to

ultimately provide a large tax base, temporary tax incentives

during the embryonic years of space development might be a

pre-requisite for private investment in such activities. During

the development phase, tax credits for research and development

expenditures could reduce the investment requirements for such a

project considerably. During the early operational stages, tax

incentives for operators could reduce financial risk, and tax

breaks for space station users could reduce market risks. These tax incentives could be phased out as the market for space operations develops, and tax revenues from space operations could eventually far exceed the value of the early tax breaks.

Other relevant government actions which would influence institutional risk include anti-trust rulings, environmental and safety regulations, and even international agreements regarding the use of space (although no such agreements have yet been ratified within the U.S.). Department of Defense interests in a private space station are another institutional matter to be considered; the military could become a major customer for space station services, or might alternatively deem private ownership of such a facility a threat to national security. The status of a privately-owned space station vis-a-vis the military would have to be determined at the earliest possible time.

Figure 2

MAJOR ELEMENTS OF RISK IN A SPACE STATION VENTURE

Type of Risk	Manifestation	Possible Government Solutions
TECHNICAL	Uncertainty involved in development and operation of complex space station systems such as space-based Orbital Transfer Vehicles and Materials Processing in Space hardware.	Support ongoing science and technology programs and facilitate transfer of science and technology to private sector through programs such as Technology Transfer.
MARKET	Uncertainty regarding the ability of space station operators to sell their services for a profit.	Guarantee markets for certain services by agreeing to use the space station, and help station operators to track industrial and technological trends.
FINANCIAL	Uncertainty with regard to the investment level, returns, and payback period of a space station venture.	Share space station costs with private sector whenever in the public interest.
INSTI-TUTIONAL	Uncertainty regarding availability of Shuttle flights; space station tax status; anti-trust, indemnification, and other legal rulings; etc.	Maintain an affordable and reliable Space Shuttle fleet and offer tax incentives to space station financers, operators, and users whenever possible.

IV. Space Station - Other Considerations

The attractiveness of a space station venture to the
investment community shall be judged over the next several years
primarily on the basis of the factors discussed in the previous
two sections. Clearly these are but a few of the many important
considerations affecting a project of such magnitude and scope.
The government will have ample opportunity to influence investor
attitudes toward the marketing of space operations, becoming, to
a certain extent, a partner in any space station enterprise.

In addition to the investment and risk considerations
previously discussed, there will be a number of other factors
affecting space station investment decisions over which the
government and industry will have little control. One such
factor is the rate of interest. When the rate of interest is
high, as it is now, long-term projects become unattractive
relative to short-term business ventures. The discounted
present-value of any income stream rapidly approaches zero, due
to the oppportunity cost of forgoing other high-yield
investments.

Consider, for example, the income streams of two
hypothetical investment opportunities (See Figure 3). Option A
is a short-term project requiring an investment of $200 million
per year over five years (years 1 through 5), and yielding an
income of $300 million annually over the following five years
(years 6 through 10). Option B is a longer-term investment

Figure 3

COMPARISON OF TWO INVESTMENT OPPORTUNITIES (SHORT- AND LONG-TERM) UNDER VARIOUS INTEREST RATES

Interest Rate	Option	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Present Value
0	A	-200	-200	-200	-200	-200	+300	+300	+300	+300	+360						$0.5 B
	B	-200	-200	-200	-200	-200	-200	-200	-200	-200	-200	+800	+800	+800	+800	+800	$2.0 B
5%	A	-190	-181	-173	-165	-157	+224	+213	+203	+193	+184						$151 M
	B	-190	-181	-173	-165	-157	-149	-142	-135	-129	-123	+468	+445	+424	+404	+385	$582 M
10%	A	-182	-165	-150	-137	-124	+169	+154	+140	+127	+116						-$52 M
	B	-182	-165	-150	-137	-124	-113	-103	-93	-85	-77	+280	+255	+232	+211	+192	-$59 M

opportunity requiring an outlay of $200 million per year over ten
years (years 1 through 10), with a payback of $800 million per
annum during the five years afterward (years 11 through 15). The
undiscounted present values of Options A and B are $0.5 billion
and $2.0 billion respectively, that is, if the interest rate were
zero, the value of Option A would be $0.5 billion, and Option B
would be worth $2.0 billion. With an interest rate of zero,
Option B (the long-term investment) would clearly be the better
opportunity, with four times the value of Option A.

Consider what happens, however, as the interest rate rises.
At an interest rate of 5%, the discounted present value of Option
A is $151 million, and Option B is worth $582 million. The
long-term investment is still superior, although the value of
each investment is less than one-third of its undiscounted value.
If the interest rate were to rise further to 10%, the present
value of each investment would drop below zero, and Option B
(present value: -$59 million) would no longer be superior to
Option A (-$52 million). Similarly, a long-term space station
project which appears attractive relative to other investment
opportunities when the prevailing interest rates are low might be
less attractive, and perhaps highly unprofitable, at higher rates
of interest.

The rate of inflation is another factor which would
influence the attractiveness of a space station enterprise. By
the time a space station becomes operational, its services might
be far more expensive to provide than originally anticipated.
The cost of a Space Shuttle flight, as an example, will probably

be several times more expensive than was originally expected, due
to the combined effects of the general inflation rate and real
increases (over the rate of inflation) in the cost of the
program. The aggregate impact of the inflation rate and real
cost overruns could similarly reduce the profitability and
attractiveness of a space station venture.

Any entrepeneurs considering a space station investment
would also need to consider their enterprise from a non-business
perspective. The social costs and value of such a project would
have to be taken into account, especially in light of the
government support which would undoubtedly be sought by any
investors in such an enterprise. NASA, for example, would
probably be more inclined to support an effort to produce
life-saving drugs in space than to support a scheme to
manufacture "space-jewelry" or other novelty items. In a broader
sense, entrepeneurs proposing to "help" NASA to build a space
station would almost certainly be asked to demonstrate how their
participation in such a project would benefit space station users
or the general public.

A space station venture unlikely to generate benefits for
society would probably receive little or no support from NASA or
other government agencies, and might even run into government or
public opposition. Competing efforts from more public-minded
private investors might further undermine an endeavor which
failed to reflect the public interest. Just as NASA would
require insight into the businessman's perspectives on such a
project, the private sector would need to be sensitive to NASA's

public mandate in order to work effectively with the government

on such a project.

V. Summary

The investment level, risk management, and other considerations outlined in this report provide a lens through which the space station concept can be viewed from a business perspective. Government and industry should work together over the next several years to focus this lens, to determine the most effective private sector role in space station development. The next step in this process is for interested organizations in private industry to evaluate the space station as a business venture, an exercise which would assess the interplay of the factors described in this report, and which would be aimed at ultimately calculating the return on investment, the bottom line in any business plan. Whether or not private industry becomes actively involved in early space station programs, the government should adopt creative and flexible development strategies in order to maximize the opportunities for industry involvement in all phases of space station activities. The government is likely to find that, as its commitment to a manned space station becomes stronger, private-sector interest in space operations will also increase. When industry picks up the initiative, the U.S. Government should be supportive, since every dollar contributed by the private sector represents money potentially saved by the taxpayers, as well as a small step in the direction of space industrialization.

NOTES

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